Urban Water Supply System Performance Assessment, the Case of Asella Town, Ethiopia

Shiferaw Gosa Mengistu

A Thesis Submitted to the Department of Water Resources Engineering
School of Civil Engineering and Architecture

Presented in Partial Fulfilment of the Requirement of the Degree of Master's in Water Resources Engineering (Specialization in Water Supply and Environmental Engineering)

Office of Graduate Studies
Adama Science and Technology University

January, 2024
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DECLARATION

I hereby declare that this Master Thesis entitled "Urban Water Supply System Performance Assessment, the Case of Asella Town, Ethiopia" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Urban Water Supply System Performance Assessment, the Case of Asella Town, Ethiopia” prepared under my guidance by Shiferaw Gosa Mengistu submitted in partial fulfilment of the requirements for the degree of Mater’s of Science in Water Supply and Environmental Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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APPROVAL PAGE

I, the advisor of the thesis entitled "Urban Water Supply System Performance Assessment, the Case of Asella Town, Ethiopia" and developed by Shiferaw Gosa Mengistu hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

______________________	______________________	______________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Shiferaw Gosa Mengistu have read and evaluated the thesis entitled "Urban Water Supply System Performance Assessment, the Case of Asella Town, Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Water Supply and Environmental Engineering

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ACRONYMS

CSA	Central Statistical Agency
EPS	Extended period simulation
GIS	Geographic Information System
HC	House connection
MDD	Maximum daily demand
MOWIE	Ministry of Water, Irrigation and Electricity
MOWR	Ministry of Water Resources
NRW	Non-revenue Water
PF	Public Fountain
PHWD	Peak Hour Water Demand
WaterGEMS	Water Geospatial Engineering Modelling Software
WDNs	Water Distribution Networks
WDSs	Water Distribution Systems
UFW	Unaccounted for water
YC	Yard Connection

ABSTRACT

The irregular distribution of water is a major challenge to water management in developing countries, including Ethiopia. There are several reasons for this, such as population expansion, increasing water consumption, and lack of resources. Because of this, water utilities are finding it difficult to give their consumers a reliable and adequate supply of water. The utility of Asella town is having difficulty meeting the demands of the town's expanding population; the town is experiencing water shortages. Moreover, the water utility lacks the equipment, components, or regulations required to manage leaks effectively. Several important performance measures, including the primary physical characteristics, customer satisfaction, operation and maintenance, and water loss, are used in this study to evaluate the town water supply system's in order to concretely identify the issue and then guide it toward a solution. In order to achieve the goal, the level of customer satisfaction and the hydraulic performance of the distribution network were assessed. A combination of primary and secondary data has been found for this study utilizing a variety of software programs, including Google Earth, ArcGIS 10.7.1, GPS, and WaterGEMS. A graphical display of the results from hydraulic modeling and a modified water distribution network was created using GIS and WaterGEMS. Google Earth was utilized for the purpose of collecting and analysing data pertaining to the water distribution network. To determine the level of customer satisfaction with the town's water supply services, a random sample of 374 households was selected from the total of 14664 customers. According to a Bentley WaterGEMS hydraulic analysis, during peaks water demand, 36.30% of the water distribution system's nodes have pressure below the required minimum and 3.03% have pressure above the maximum acceptable pressure. Static pressure in pipes caused by water flows less than 0.6 m/s may encourage the growth of bacteria and debris. Moreover, 2 m/s of water flow might result in head loss and water damage. The water flow rate in the town's water distribution system was insufficient at a period of low water demand. This could result in issues including head loss, pipe breaks, water hammer, stagnant water and sediment build-up in the pipes. As a result, the water distribution network's flow velocity needs to be managed. The validation was done by the mentioned formula, and the data presented shows a significant positive correlation for both minimum demand and peak hour demand between the simulated and measured pressure during calibration. With corresponding R^2 values of 0.90 and 0.85, respectively, the WaterGEMS model was calibrated using Fifteen nodes data points at minimum and peak hour consumption. This is a good result that suggests the model is correctly representing the system's behavior. In conclusion, the water service should adopt, according to the findings of the study. The water utility should put this study's recommendations into implementation. As a result, the water distribution system will operate more efficiently and offer consumers better service.

Keywords: Water distribution, WaterGEMS, Hydraulic performance, Evaluated, Operation and Maintenance, and Asella Town

1. INTRODUCTION

1.1 Background of the Study

Water is a vital natural resource that is necessary for all life to exist, the economy for growth, and food to be produced. It continues on to say that supplying the water needs of a population that is rapidly growing is getting more difficult particularly in developing countries(Fekrudin, 2019).

The most crucial government service is ensuring that everyone has access to clean water at all times. Meeting the increasing demand for water in developing countries is getting more and more difficult for water organizations, particularly those that deliver water to the population as a whole (Abate, 2022).This is due to the population's overall growth as well as the increasing number of the population shifting from rural to urban areas (Adem et al., 2023).

Many public utility companies have been unable to supply their customers with enough water and sanitary services. The UN Millennium Development Goals for water supply, which demand for supplying clean water to all people worldwide, suffer greatly by this (Strajhar et al., 2016). Since they are not the primary consumers of urban water delivery systems, urban water utilities frequently ignore the needs of the urban poor. This is due to the fact that urban water utilities are having problems sustaining with the rising water demand(Beker, 2022).

Public utilities in poor nations frequently struggle to provide their consumers with adequate access to clean water and stable methods of waste disposal. These utilities have difficulty carrying out their duties effectively due to the total number of other problems such as pipes that are leaking water. In addition of the high population density and unsanitary living conditions in developing countries, these issues are particularly difficult for urban water utilities(Saleem et al., 2020).

Water leaks and other forms of unaccounted for water (UFW) reduce the amount of water that water utilities have available to sell to their consumers, which may result in lost revenue. Public service providers have frequently been unable to supply their citizens enough water or sufficient sanitary facilities in developing countries. Population expansion and the growing demand for urbanization have made these issues worst (Lu et al., 2018).

Water losses at all stages of the distribution system present a significant difficulty for water utilities in developing nations, including Ethiopia. In terms of coverage, quantity, quality, and dependability. Ethiopia's water supply service is very poor. When planning for the present and long-term demands of the city, a well-functioning urban water supply system should be able to supply enough water for people, animals, industry, and other uses.(Ahmed, 2022). According to data from Ethiopia's Central Statistical Agency (CSA), 18% of the population lived in urban areas in 2007. This proportion is always rising. Ethiopia's water supply has increased by 57%, with a 97% increase in urban areas and a 42% increase in rural areas, according to the UNICEF Joint Monitoring Program 2014 Report(Desalegn, 2015). A water distribution system is a network of pipes, pumps, and storage tanks that distributes clean drinking water to customers and other users from a single source. Gravity storage feed, distribution pumping networks, and balancing storage are all included in it, along with everything else required to transport and deliver safe drinking water to customers. (WDN) design as well as study are crucial since the general public's health depends on their efficient operation. (WDS) are crucial in ensuring that everyone has access to safe drinking water, which is essential for maintaining human health and sanitation (Mukherjee et al., 2022).

A hydraulic infrastructure termed a water distribution system is a sophisticated system that includes pipes, valves, pumps, tanks, and reservoirs that transports drinking water from its source to consumers. It's crucial to plan and manage water distribution systems so that they can continue to serve the community's demands over time and in a variety of circumstances. (Tsige, 2022).

Generally, rapid population increase, water loss from the distribution system, and other factors, there is often a gap between the demand and availability for water in developing nations. According to the water delivery services in Asella is having difficulty meeting the demands of the town's increasing industrial and population growth. Water interruptions pipe failures, and insufficient coverage have all been complained about by the residents. Therefore, the goal of this study was to assess the operation and maintenance of the town's water supply system, as well as customer satisfaction, and to find additional indicators that could be used to assess the performance of the existing water supply distribution system and identify areas for improvement.

1.2 Statement of the problem

In many developing countries, public service providers have found it difficult to supply enough sanitary facilities or enough water for consumers. Adding to these issues are population growth and the increasing demand for urbanization. To do this, the urban water supply system's performance must be assessed. Urban water supply systems in developing nations, like Ethiopia, suffer the following main challenges; Under-serviced water supply infrastructure, not having enough water available at all times and extremely high-water loss rates, as much as 50%–60% of the supplied water (Saketa, 2022).

According to, Asella town water supply system that even weeks or long of time shortages of water is common. In addition, there is constant pipe bursts and significant water loss in the distribution system. The water pressure and velocity might vary greatly due to the older structure. The town is expanding population and uneven water supply, it is challenging to provide basic water services. There is lack of water in Asella as a result of the town's rapid urbanization and population growth. The water distribution system does not provide water to every area of the town, and the town's water supply is insufficient to satisfy the current demand. In Asella, there are some villages without access to water pipelines, and water interruptions are frequent. Additionally, the town's water provider is having financial difficulties as a result of low water rates, poor service, inaccurate customer data, and inefficient billing and collection procedures. These issues have detrimental effect on the performance of the current water distribution system. As a result, it is necessary to assess the current hydraulic performance of the town's existing water distribution system.

1.3 Objective of the study

The primary goals of this study are to achieve the following general and specific objectives by assessing the Asella's water distribution systems.

1.3.1 General objective

The general objective of this study is to evaluate the performance of the Asella town water supply distribution systems.

1.3.2 Specific objectives

- To assess Asella Town's water supply distribution system hydraulic performance
- To determine how satisfied customers are with the water distribution service
- To assess the water supply system's condition of operation and maintenance

1.4 Research Questions

Specific objectives of the study would help achieve it finding the answers to the following questions: -

1. How well-performing is the hydraulic system of the water supply in terms of pressure and velocity?
2. How do you think about the supply, prospective consumers?
3. What is the key maintenance and operation challenges?

1.5 Significance of the study

The purpose of this study is to assess the town of Asella's water distribution system. The investigation will determine any systemic problems, including the estimated amount of unaccounted water and the causes why water is being loss. Additionally, it will evaluate the level of service and coverage of the water supply. A performance evaluation system for evaluating and effectively improving the water distribution system will also be developed as part of the project. In order to assess and analyze results and projections, the study will identify knowledge gaps and indicate areas that need more research. Alongside ensuring that customers are satisfied with the service, operation, and maintenance state. In general, this research will assess Asella Water Supply in enhancing the efficiency of its water distribution system and reducing its supply shortage.

1.6 Scope of the Study

This study evaluated the effectiveness of water supply and demand as it assessed the efficiency of urban water delivery systems in a particular area. Also, the study concentrated on hydraulic conditions, assessing performance under peak hour consumption and minimum consumption time, and water quality from its assessment. It was believed that the water delivered to consumers were high quality, and all people used water from the town's existing water supply distribution system.

1.7 Limitation of the Study

The study's funding availability was insufficient to collect field data for the whole distribution network for validation. Due to a lack of sufficient written material or writings from local sources in the field. Getting sufficient and necessary primary and secondary data is another significant problem. The following are these difficulties: -

- Some legislative offices refused to give the necessary quantity and quality of data. The administrative offices kept poor records of the information, which made it difficult to find basic and relevant information.
- Exchanging government workers from one place to another, as well as from positions to positions. The study's primary limitations were these.

1.8 Organization of the Thesis

There are five chapters in the thesis. The first chapter covers the paper's introduction, which includes the background information, objectives, statement of problem, research questions, study scope and limitations, and paper organization. A survey of the literature is covered in Chapter tow. The study area and methodology are introduced in the third chapter. The study area description, data sources, software utilized, image preparation, and classification are all covered. The focus of chapter four is on discussions and results. The study's conclusion and recommendations are the main topics of the final chapter.

2. LITERATURE REVIW

2.1 Evaluations of the performance of urban water supply systems

The development of appropriate performance indicators is essential for assessing the efficiency of a water supply system in an urban area. Three categories can be formed out of these indicators: operational performance, physical performance, and performance of water resources(Joshi & Mishra, 2020). The availability of water resources and the system's ability to access them are measured by water resources performance indicators. The quantity and quality of water delivered to customers are measured by physical performance indicators. The efficiency and reliability of the system is assessed using operational performance indicators(Strajhar et al., 2016).

Physical performance in a water supply system relates to the quantity and quality of water distance located in the homes of customers as well as the storage facilities' capacity and transmission and distribution lines' quality. On the other hand, operational performance relates to the system's operation and maintenance as well as the standard of the water supplied to customers.(Olukanni et al., 2014).The study of urban water supply utilities In Ethiopia found serious problems with water service in the different regions analyzed. The study focused on unaccounted-for water (UFW) and service quality as its two key indicators. UFW and quality of service have been referred to as two important measures of water utility performance.(Landa-cansigno et al., 2020).

The performance of the water utility is negatively impacted by poor water delivery, billing, and customer service, which lowers consumer willingness to pay for water. In addition to an assessment of the available documentation, the study also included field observations and household questionnaires.(Sapkota et al., 2015). However, the purpose of this study document is to evaluate the Asella town water supply system's performance. Available water sources, hydraulic performance, (WD), consumer satisfaction, and operation and maintenance will all be taken into consideration while making the assessment(Eshete, 2019).

2.1.1 Performance of water resources

Towns frequently have water supply systems that cannot keep up with increasing demand and are not accessible to everyone. Poor communities are first to suffer when consumers consume more water than they actually require. This is a result of ineffective systems, a lack of water resources, and a lack of access to private water sources by the general population. Most of Ethiopia's urban water supply and sanitation infrastructure are incorrect, and quick enough repairs and expansions are not being made. (Debela & Muhye, 2017).

2.1.2 Operational performance

A water distribution system's operation and maintenance are significantly influenced by the method it was planned and constructed (including modifications and corrections). Major problems with operating and maintaining the system may result from issues in these phases(Desalegn, 2015). Another way to assess service quality is to consider how simple it is to obtain water, how dependable the water supply is, how regularly leakage control , repaired, how effectively leakage are regulated, how respected consumers and workers are, and how much the service costs(Rata & Brook, 2018).

2.1.3 Demand and Urban Water Coverage

2.1.4 Urban water coverage

Water supply coverage shows how much to every country or community has access to piped water. It is an important tool for comparing different countries and cities, as well as for determining how access to water is distributed within an urban area. An accurate measure of the availability of water in urban areas is the number of persons with a piped water connection. When analysing water supply coverage, it's essential to also take the volume of use and the level of water connection into consideration(Saleem et al., 2020).

These elements are closely related to the problem of water loss. When planning for water services, other variables must be taken into consideration in addition to the difficulties of ensuring network coverage and access to water (Vairavamoorthy, 2007).These consist of: -the quality of the water source is safe, whether there is enough water supply to suit the population's needs the consistency of the supply (e.g., it supplies year-round, 24 hours a day). The supply's accessibility (e.g., is it piped to residences or nearby) (Moye et al., 2020).

According to Beker (2022) states that a household has access to better drinking water if, it provides the family with 20 liters of water per person per day, less than 10% of the entire household income is needed to pay for the water. All members of the household have easy access to water, especially women and children (it takes less than an hour to collect the bare minimum amount required). Access to services for providing safe drinking water was considered poor in Ethiopia. According to Andualem (2020), only 19% of the nation's residents have access to clean drinking water in 1990. When compared to 2007, the percentage was 52%.

Table 2-1: Percentage of people in Ethiopia that have access to clean drinking water (2000– 2015)

Year	2000	2004	2006	2007	2010	2015
Urban	92.0	92.0	78.0	82.0	85.0	90.0
Rural	17.0	25.0	41.0	46.4	50.0	60.0
Total	28.0	36.0	47.3	52.5	62.5	75.0

(Source: MOFED 2007)

2.2 Water Demand

System water demand, according to Gebrehiyot (2015), is the volume of water a treatment plant has to produce in order to supply all of the water needs of the community. Water delivered to the system to meet customer needs, water utilized for firefighting, water used for system flushing, and water required for the efficient operation of treatment facilities are all included in this. The overall demand often includes the fact that every system contains certain leaks that are too expensive to repair (Belayneh, 2021).

2.2.1 Classification of Demand

Demands for household water, non-domestic water, and non-revenue water are categories for the water that is used based on the customers and the purpose of the water consumption. Consider the following techniques for assessing the projected water demand for various demand categories.

2.2.1.1 Domestic Water Demand

Domestic water demand is the amount of water used in a household for drinking, cooking, cleaning, bathing, and other various domestic tasks. The amount of water used for residential purposes is significantly influenced by the users' way of life, standard of living, climate, mode of service, and affordability of the uses (Saketa 2022).

2.2.1.2 Non-Domestic Water

The demand for non-domestic water (the water needed for public facilities like schools, hospitals, health centers, government offices and services, and places of religions) had been determined systematically. According to the Asella Design Report (2009.Generally, it divides into three main categories: commercial, industrial, and institutional water demand.

2.2.1.3 Industrial Water Demand

Projects involving town water supplies will be under a lot of strain from industrial activity. Because of this, if they are to be implemented in the town, it is advised that they have their own sources. Even so, small-scale businesses like restaurants, flour mills, and oil extraction facilities are classified as institutional and commercial, and the municipality will provide services for them (Belayneh, 2021).

2.2.1.4 Water Demand for Livestock

The Bosha River flows intermittently, but all the streams that are currently present in the town's surroundings, like Kombolcha and Hanku, are perennial. These water supplies therefore provide the majority of the water used by the town's livestock. But during the quick socioeconomic study, the socioeconomic group identified that certain town residents who don't let their animals to graze use the municipal water supply as a source of feed.

2.2.1.5 Water Demand for firefighting

Firefighting requires a relatively small volume annually, but at times of need, demand may increase to extremely high levels, which can often the distribution storage and pumping requirements. Water flow in the distribution system, fire incidence, duration, building density and size, and building construction materials are the primary elements that determine the volume of water needed for preventing fires. Various methodologies have been developed by different institutions to assess the demand for fire protection in a given area based on these characteristics.

2.3 Urban growth and Water supply

In previous periods, people have established towns around freshwater resources including springs, rivers, lakes, deltas, and coastal regions. however, water is a non-renewable natural resource and the risks associated with it are growing due to the effects of the climate change and expanding urbanization. Despite the rising concern about water-related concerns around the world, Ethiopia mainly ignores and understudies problems.(Abraha et al., 2022).The need for water increased as settlements expanded into large towns and cities for both domestic and industrial uses. The need for water for household use grew as industry developed and more people relocated from rural to urban areas to work(Kidanie, 2015).

2.4 Distribution System Hydraulic Performance Analysis

The town of Asella's water supply system was studied using the Bentley WaterGEMS software, a tool for modeling water distribution systems. since of its integration with ArcGIS and AutoCAD software, WaterGEMS is a common choice since it enables users to view the output of their models using a range of graphical tools, including ArcGIS maps(Saketa, 2022).The Town's Water Supply Administration Office provided the AutoCAD model for the planning of the water distribution system. The hydraulic modeling program Bentley Water GEMS was then used to import the network using the model builder toolbar. The network was then converted to Bentley WaterGEMS format, and the most crucial (Abate,2022).A water distribution system a network of pipes that transports water from one or more sources to consumers. The water level in the pipes has a significant impact on the system's operation. The performance of a different system is influenced by both the water level and the flow rate. Groundwater wells, storage containers, and reservoirs are typical sources of water supply (Cardoso et al., 2014).

2.4.1 Drinking water is distributed unevenly in urban water supply systems

It is the other significant issues impacting the town's WSS office. The town of WSSo water supply system is insufficient to satisfy residents' needs. There are areas of the town without any access to water because the distribution infrastructure cannot keep up with demand. This poses a serious problem for the community because it makes it impossible for them to meet their most basic needs (Debela & Muhye, 2017).

The study town's water distribution system is not distributed equally. It is only available in the town's center and in a few government-owned homes, buildings, businesses, and NGOS. Not all areas of the town have access to it, particularly the newly enlarged areas and the majority of the border areas. This indicates how unjust or unfair the town under study's water distribution system is(Mukherjee et al., 2022). A number of problems, current as well as past, affect the town's water distribution system (Andualem,2020). Due to improper distribution pipeline installation in relation to the town's geography, the pipelines are constantly being damaged by water pressure.

2.4.2 Components of water distribution network

The water distribution system (WDS)is a critical part of urban infrastructure. Water contamination or pipe bursts can have a serious harmful social and economic impact. For existing WDNs to operate effectively, operation, maintenance, and rehabilitation planning is necessary(Beker, 2022). A water distribution system (WDS) can supply water to customers using gravity, pumping, or a combination of the two. The geography of the area affects the system choice. Delivering clean water to users in appropriate quantities and at a sufficient pressure is the primary goal of a water distribution system. Urban security cannot be achieved without ensuring a WDS's security.(Li et al., 2022**).** Transmission mains and distribution mains are the two main piping types used in water distribution systems. Water is transmitted through mains from the source to storage facilities or pumping operations. Water is distributed to individual consumers by distribution mains from storage tanks or pumping stations.

- **Transmission**

Transmission mains large pipes that transport water across great distances from water treatment facilities to reservoirs and storage tanks. They can be up to several feet in diameter and are commonly built of ductile iron, steel, or concrete. Typically, transmission mains are placed underground to protect them from harm and stop pollution (Belayneh, 2021). .

- **Distribution mains**

Distribution main the intermediary pipes that transport water from the main water supply to your home. Although they are not as huge as the main water supply pipes, they may ultimately transport a lot of water. In a town or city, distribution mains usually lie beneath the streets. Various fittings, including elbows, tees, reducers, and crosses, are used to connect them to one another.

- **Reservoir and storage tanks**

Storage tanks and reservoirs are crucial parts of water distribution systems. They perform a number of crucial tasks, such as: - adjusting for variations in water demand: Seasonal and daily variations in water demand must be considered. Even during times of high demand. They also assist ensure that there is always enough water to satisfy customer needs. Reservoirs and storage tanks aid in stabilizing the distribution system's pressure by helping to keep it consistent. This is crucial for stopping leakage and other issues. Emergency water supplies: - In case of an emergency, such as a power outage or a break in the water main, reservoirs and storage tanks can offer a reserve of water.

- **Pump Stations**

Pumps are devices that use energy to transport water to higher altitudes. Gravity frequently is unable to supply water at the right pressure; therefore, this is necessary. The most common type of pump used in water supply systems is a centrifugal pump. These pumps are put in place to ensure that everyone has access to water at an appropriate pressure and to improve water distribution. Switchboards are set up in the pump station to manage the functioning of the pumps.

2.5 Water Demand Factors

2.5.1 Average Water Demand

The average daily water demand is the whole amount of water consumed daily, including water used for households, businesses, and other uses as well as water wasted due to leakage or other issues. This data is used to determine the peak hour demand, which is the most water that will be used in any given hour, and the maximum day demand, which is the amount of water that will be consumed at any given time.(Belachewa et al., 2021).

2.5.2 Maximum Daily Water Demand

The highest amount of water consumed in a particular year on a single day is known as the maximum day demand. When building water supply systems, it's critical to determine the daily maximum demand so that the systems may be built to withstand the peak demand. That need daily water consumption data for the area that are interested in in order to determine the (MDWD). Others can utilize maximizing coefficients from a design guideline if this data isn't accessible. A table of maximizing coefficients for various types of places, such as residential, commercial, and industrial regions, will often be provided in this recommendation in the table 2.2 below.

Table 2-2: Maximum daily demand factors

Population	Maximum day factor	Peak hour factor	Remarks
0 to 20,000	1.30	2.0	Small towns
20,001 to 50,000	1.25	1.9	Moderate town
50,001 to 100,000	1.20	1.8	Large towns
100,001 and above	1.20	1.6	Large town

Source-(Urban Water Supply Design Guidelines, by Ministry of Water Resources January 2006)

Maximum daily demand (MDD)

Peak factor (Pf) = $\frac{Qmax}{Qavg}$ ---(2.1)

Where: -

Pf……. Peak factor

Qmax…. The maximum daily demand as determined on several days.

Qavg…. Average daily demand

2.5.3 Peak Hour Water Demand

The most water is used during peak hour demand of any hour of the year. It is brought on by how frequently people consume water. (PHWD) is influenced by a town's size, water delivery system, and social activities. (PHWD) is higher in smaller towns than in larger towns, according to studies. Peak hour demand is higher in smaller towns, according to experience. Based on the average daily demand, the peak hour factor is a multiplier that is used to determine the (PHWD).

2.6 Water loss

Even new water distribution systems suffer water loss. The effectiveness of the water authority's network management will determine how much water is lost. Real and apparent losses of water can be distinguished (Nigussie, 2017)in two categories.

- **Real losses are**: - actual water losses from the distribution system, like leaks in the pipes and valves.

- **Apparent losses are: -** water that is not accounted for, such as through illegal consumption and metering problems.

Non-revenue water (NRW) levels are a crucial indicator of efficiency for the majority of water companies. It is total amount of water produced but not billed to customers. In order to assess each component of water losses and identify their locations, utility management need apply the water balance method. The average amount of water used per person and the percentage of persons with access to water connections were initially calculated by the investigators. The overall amount of water lost was then determined. They gathered all the required information, including the quantity of delivered and consumed water, to do this. (Demeku et ., 2021).

The water balance equation can be used by utility managers to compute each element of water losses and identify their locations. The following is the water balance equation: -

Water produced = Water billd + Real losses + Apparent losses ----------------------------------(2.2)

2.6.1 Causes of water losses

In undeveloped and partially developed countries water loss is frequently brought on by illegal connections, faulty meters, and accounting problems, rather than physical leaks. Meter under-registration, illegal water consumption, and unknown water use are additional elements that may cause unaccounted-for water. (UFW), whether or not it is metered, is the differences between the amount of water delivered into a water system and the amount of water used for legal purposes.(Tsige, 2022).In all water delivery systems around the world, water loss is a common issue. Because pipe connections are not perfect, it happens in all water distribution networks. This can be because of poor installation or maintenance, poor quality of the materials used, or both.(Coelho, 2014). Up to 10% of the total production's water loss is accepted. Water loss between 10% and 25% is considered as moderate and has to be reduced. A severe concern occurs and immediate action is required if the water loss is higher than 25%.(Ahmed, 2022).

2.6.2 Non-Revenue Water

Non-Revenue Water (NRW) is :- water that enters a water utility's distribution system but is lost before it reaches paying customers(Joshi & Mishra, 2020). NRW may occur for a variety of causes, such as: -

- **Water supply system leaks: -** Over time, pipes and other infrastructure may develop leaks, causing water to be lost.
- **Illegal connections: -** some persons could access the water supply system illegally in order to avoid paying for water.
- **Reservoir overflow: -** when there is a lot of rain, reservoirs may overflow, losing water.

- **Improper metering: -** water utilities may lose money due to faulty water meters that underreport water usage. Water might be lost during the water treatment process, or losses in the treatment plant(Rata & Brook, 2018).

NRW = System Input Volume − Billed Authorized Consumption -----------------------------(2.3)

Unaccounted for Water is the amount of water produced but not accounted for as having been provided to customers. It is computed by dividing by the total water generated, multiplied by 100, and then reducing the metered customer consumption from that total. This is the percentage of total produced water that is UFW.

$$\% \text{ Unaccounted for Water} = \frac{\text{Water Produced} - \text{Meter Used} * 100}{\text{Water Produced}} \text{ -----------------------------------(2.4)}$$

2.7 leakages

Regardless of the size or location of the system, water loss is a common problem in water distribution systems. Leakage, which can happen at pipes, connections, fittings, and reservoirs, is the main reason for water loss (Farley et al., 2010). Several things, including the following, can result in leakage: -

- **Lack of maintenance: -** to avoid leaks, water distribution system pipes and other parts need to be constantly analyzed and maintained. Without regular maintenance, pipes and fittings can corrosion or suffer other damage that makes them leak.
- **Systems that become older: -** Many water distribution systems are a long time, and the pipes and other parts may be past their usefulness. In particular, if they are neglected, old pipes are more likely to start leaking (Dighade et al., 2014). Poor management of pressure zones is one of the causes of water leaks. This may lead to the failure of pipes or pipe junctions. People should report any visible leaks because some breaches may go unreported for a long period. This must have significant public support in order to be successful. The entire amount of water wasted is also impacted by leaks that occur after the water meter (Nigussie, 2017).

2.7.1 leakage from transmission and distribution mains

Large leaks may occur in the main pipes that transport water from treatment facilities to households and commercial buildings. This is due to the pipes' age, poor construction quality, or improper installation. Water supply may become irregular as a result of these leaks, which can lower water pressure in the distribution system (Dighade, et al., 2014).

2.7.2 Leakage from storage tanks and reservoirs

It is simple to measure leaks and overflows from storage tanks and reservoirs. Utility professionals can observe overflows to predict their duration and flow rate. It is crucial to periodically check reservoirs at night because most leaks happen then when demand is low. Manual inspections are possible, as well as installing a data recorder that automatically records reservoir levels on a regular basis (Kefyalew, 2019).

2.8 Operation and Maintenance

Ethiopia is among the huge majority of developing countries where infrastructure services are provided by state-owned businesses. On the other hand, considering they lack a formal customer service strategy, government-owned businesses usually place a low focus on the needs and satisfaction of their customers. consumer satisfaction is determined by the business's or utility's real performance, which is an evaluation of the good or service offered in regard to the needs of the customer as a whole. The maintenance and operation of urban water supply systems is of utmost importance, with water distribution systems requiring particularly complex O&M(Demeku et ., 2021).

A system's O&M requirements are greatly influenced by the way it is designed and constructed, according to what said. Water loss, expensive repairs, and service interruptions can result from leaks, breaks, and other problems with poorly planned or built systems(Joshi & Mishra, 2020). some key points to consider about O&M in water distribution systems: -

- **Preventive maintenance: -** Regular inspections, cleaning, and repairs can help to prevent problems before they occur. This is often more cost-effective than dealing with major breakdowns later on.
- **Leak detection and repair: -** Leaks can waste a significant amount of water and can also lead to damage to infrastructure. Having a system for detecting and repairing leaks quickly is essential.
- **Water quality monitoring: -** Maintaining water quality is essential for public health. Regular testing of the water is necessary to ensure that it meets safety standards.

2.9 Maintenance Practice Method

The techniques used by the towns water service offices to manage water distribution leakage have been assessed based on a number of variables, including management, technical, financial, strategic, regulatory, and objective considerations. In order to find system and management process leakage, field investigations were carried out. Workers of the local water supply service were interviewed during the field inspection to get additional information about the system's frequent failures, funding sources, maintenance culture, and cost-related maintenance variables. Analysing the utility's operating and annual reports allowed for the collection of cost-related information.

3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

Assela is located in the Oromia Regional State of Arsi Zone at 75 km from Adama and 175 km from Addis Ababa. The town located at 7°57′ N latitude and 39°07′30″ E longitude at an average elevation of 2,300 m. as shown in (Fig-3.1).

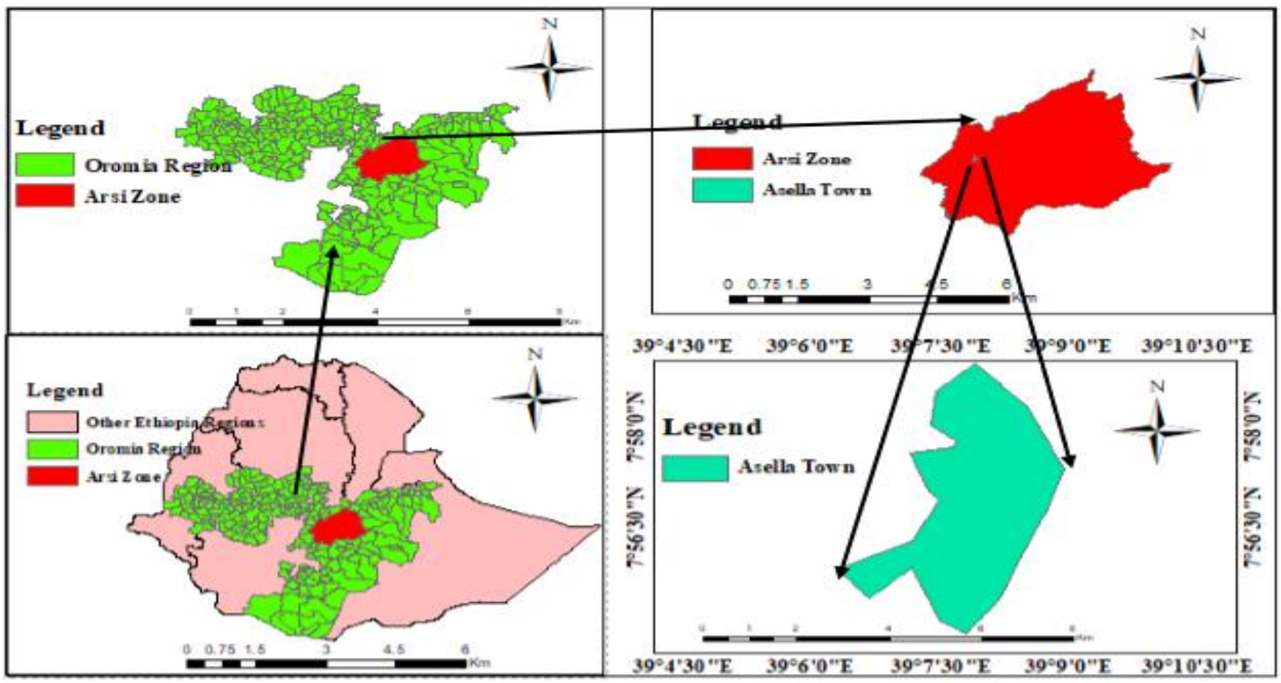


Figure 3-1: Map of study area

3.1.2 Climate

Asella town's climate is described by its location in the wainadega to dega ecological zone of the entire country. There are four distinct seasons in the climate: Bulge (low rainfall from March to May), Bega (dry season from December to February), Tseday/spring (from September to November), and Kermit (rainy season from June to August). The region's average annual rainfall varies geographically, ranging from 456mm in lowland regions to over 832mm in highland regions. At Asella station, the average daily temperature is also fluctuating, ranging from 17.10C to 19.60C.

3.1.3 Topography

Asella study area is bounded in the NE by the Awash River Basin and in the E by the Rift Valley River Basin. The rift valley lakes and Awash rivers basin are separated by the watershed by the North-South elongated volcanic mountain chain, or Chilalo Mountain. The area can be classified as plateau, rugged terrain, mountain chains and the rifts low land plains.

3.2 Research Design

This study was designed to respond to the expanding requirement for accurate information when assessing the hydraulic performance of water distribution systems. In order to understand the research concerns more thoroughly, it used an integrated methodology that included both qualitative and quantitative methods. The first step was to determine the amount of water the town needed for the current year while taking into consideration each mode of delivery. The annual water consumption per resident of the town was then determined using this data.

After that, a percentage of the water loss was determined. Water production as a whole and actual consumption were measured using customer meters in order to investigate water loss. Following that, the simulation was analysed, including the model's validity, the determination of the hydraulic parameters, and the level of water service customer satisfaction. Finally, the performance of the water distribution network was evaluated using accepted standards.

3.3 Distribution of the population by service mode

The following reasons cause changes in the percentage of the population who use each form of water supply over time: -The capacity to grow the water supply service, changes to building regulations, and service level improvements. Although majority of households obtain their water from within the house, some also make use of public fountains (PF) or common yard taps (YC). The supply connection pattern was categorized into three groups based on all of these. factors: (HC) House connection; (YC) Yard connection; and Public fountains. (PF)

The table below shows how the many types of water services that are currently offered are grouped based on the proportion of current total water coverage.

Table 3-1: Percentage mode of services based on current of population served.

Mode of Service	Percent of population served (%)
HC	37.3
YC	36.9
PF	21.0

Source:(Asella town water service enterprise 2012 report)

3.3.1 Evaluation of the Hydraulic Performance of the Distribution System

The hydraulic performance of the network over an extended period of time was analysed as well using WaterGEMS. This made it possible to predict how the network would function in various situations such as those brought on by increasing demand or changing weather patterns. The pressure system, demand, velocity, and head loss of the town's water distribution network have been estimated and evaluated with

WaterGEMS V8i. This made it easier to understand how the network functions and to identify areas that needed development. WaterGEMS was used to import GIS data and GPS measurements of the town's water sources, reservoirs, and pumping facilities. Following that, each node's land area is measured and identified using the land use map, and the results accumulate under each category. Each category's overall water usage is then computed. Finally, the demand area ratio for each category is computed, assuming a uniform population distribution.

3.3.2 Model calibration and Validation

Calibration was done in compliance with USEPA water distribution system calibration recommendations by using a portable pressure gauge to obtain readings at 2-10% of all nodes, from low pressures to high pressures. After then, minor adjustments were made to the sensitive parameters (pipe roughness and nodal demand) to make the simulated results more similar to the real or field results. After the first run, the water demand and pipe roughness coefficient two sensitive flow-related parameters were adjusted in the Darwin calibrator until they were within the allowed ranges. Finally, the model data was analysed in order to compare and calibrate the computed pressure data with the actual measured pressure data. Using a Microsoft Excel sheet and the correlation coefficient equation (R2) approach, the validation was carried out manually. The following formula was used

$$R = \frac{\sum(X-X^{-})(Y-Y^{-})}{\sqrt{\sum(X-X^{-})^{2}} * \sqrt{\sum(Y-Y^{-})^{2}}} \text{ --(3.2)}$$

Where, R is the coefficient of determination, X and Y are the computed and observed pressure values, and X¯ and Ȳ are the mean values of the computed and observed pressure, respectively. State that in order to bring the sensitive flow parameters such as the water demand and pipe roughness coefficient within an acceptable range of 85% of field test readings, the calibration process was carried out.

3.3.3 Analysis of the steady state simulation

The model was tested using a steady-state simulation analysis for peak hour demand and average daily demand. This means that it was believed that the demand at each node would remain constant over the course of a 24-hour period. When a system is in a steady state, when flow rates and hydraulic grades are constant over time, steady-state analysis is performed to ascertain how the system will operate at that point in time or under those conditions.

3.3.4 Extended period simulation analysis (EPS)

In practice, steady or constant border conditions are uncommon. This implies that there is an opportunity for gradual changes in the environment at the system's borders. A simulation that is EPS, or event-driven simulation, is one that is started by events like a change in supply or demand. Every 24 hours, the system's state was determined and evaluated by EPS. This indicates that EPS was used to monitor how the system changed over time.

3.3.5 Current Sources of water and Main Transmission

3.3.6 Current sources of water

Under the current water system, from the Ashebeka river to delivered an open balancing chamber inside the treatment plant compound on the southern edge of town. Following the study and design phase, EWWCA was given a contract in 1986EC to build a new system based on the Ashebeka River. The project was completed and officially opened in 1990EC, marking the beginning of project operation and functioning. The new system has a 10-year design life. EWWCA implemented water supply facilities with the 1986EC to 1990EC, including a 34.2km transmission and falling mains network from the Ashebeka River to the Asella treatment plant, totaling around 36.53km of distribution network (determined from the as-built drawing). Asella's present water supply source is completely incompatible with the town's overall water demand.

The estimated 350 m3/hr of Ashebeka raw water that is now planned to be transported to the balancing chamber is far less than the town's required water demand. Even said discharge varies from day to day and season to season due to power changes at the pumping station and river discharge. On the other hand, during a site visit, the river's optimal discharge was determined using a broad crested weir discharge measurement approach and was estimated to be around 303 l/s.

3.4 Materials

This study's primary objective aimed to evaluate the effectiveness of Asella's current water distribution system. The research used a GPS device to record elevation information alongside pressure readings taken with a pressure gauge. This approach allows for analyzing the relationship between pressure and elevation, which can be crucial in understanding the water flow constant change within the distribution system. To gather, arrange, and analyse the data, which used tools including WaterGEMS, Arc GIS 10.4.1, AutoCAD, and Microsoft Excel**.**

Google Earth: - was utilized for the purpose of collecting and analysing data pertaining to the water distribution network. Locations of pipes, their diameters, variations in elevation, and other relevant features might all be included in this.

ArcMap and WaterGEMS: - were utilized for data visualization and analysis. Creating a map of the distribution network overlaid on topographic map of the town probably the process around it. One possible application of WaterGEMS would have been for network performance analysis or modified hydraulic modeling.

3.5 Methods of data collection and Analysis

3.5.1 Population forecasting

In order to determine an accurate estimate of a place's population size, one must know how many people live there, how quickly that number changes, and how the population is distributed. The main causes of these changes in Ethiopia are births, deaths, and migrations. Forecasting future population has frequently depended on techniques like exponential growth models or the CSA approach in developing countries where towns can increase quickly. Thus, whatever of these approaches yields the most accurate findings will probably be the best technique to estimate the population of Asella town. The following is how the exponential population forecasting approach is expressed: -

$$Pt = Po * e^{rt} \quad \text{---}(3.1)$$

Where Pt = is the projected population at time t

Po = is the initial population at time

e = constant, the base of natural logarithm

r = is the annual growth rate

t = is the number of years

3.5.1.1 Sources of primary data collection

Field observation and measurement: - More relevant data on the topic has been shown by the pressure reading, the elevation assessment, and the discussions with water staff members.

Surveys of households and questionnaires: - This specific technique is used to collect information from a sample of houses or responders. The questionnaires can be divided into several categories, including the respondent's 14 kebeles, the source of their drinking water, their level of customer satisfaction, and factors affecting the availability of drinking water in towns, such as travel time and distance to the source, waiting to fill a container, and quantity of town water supply. To achieve the objectives of customer satisfaction, respondents provided answers to the questions.

3.5.1.2 Sources of secondary data collection

The data has been gathered from a number of sources, including: - Reviews of relevant literature on the subject are known as literature evaluations, design reports are documents describing a project's or system's design, the town's water supply service office has previously collected the following records and documents that provide an annual report on the operations of a business or organization

3.5.1.3 Assessment of customers satisfaction with the current water supply system

Samples for the investigations were obtained from households with connections to the water supply and from 14,664 customers who have taken 374 from part in 14 the kebeles. A statistical method was used to determine the sample population (Cochran WG, 1977).

$$n=\frac{Z^2*p*q*N}{(N-1)*e^2+Z^2*p*q} \text{---} (3.3)$$

Whereas, n (i)---- is the sample household (sample size)

N…….is total number of households

P……. (P is taken as 50%),

Q…….1-P

Z……...95% confidence interval (1.96)

W or e.......complete error or precision, 5%

$$n=\frac{1.96^2*0.5*1-0.5*14664}{(14664-1)*0.05^2+1.96^2*0.5*1-0.5} = 374 \text{ households}$$

3.5.2 Satisfaction of Costumers analysis sample selection

A systematic random sample of 374 households was chosen from all (14) kebeles to assess how satisfied they were with the water delivery service in Asella town. Customers' opinions on the standard, quantity, availability of water, and affordability of the water were gathered through surveys. Officials interviewed people in order to get their opinions on the effectiveness of household customer connections, problems with pressure and availability of water supplies, and problems about water quality.

3.5.3 Evaluation of customer satisfaction methods

Using prepared questionnaires, the customer satisfaction evolution's primarily assessment will be made. In addition, questionnaires are generated and distributed, and the results are analysed to the town's the residents. The questionnaires are distributed using a systematic random sampling method, but all of the system area is taken into consideration and the questions are analysed using an Excel chart. The results have been presented through tables and graphs.

3.6 Conceptual Framework of the Research

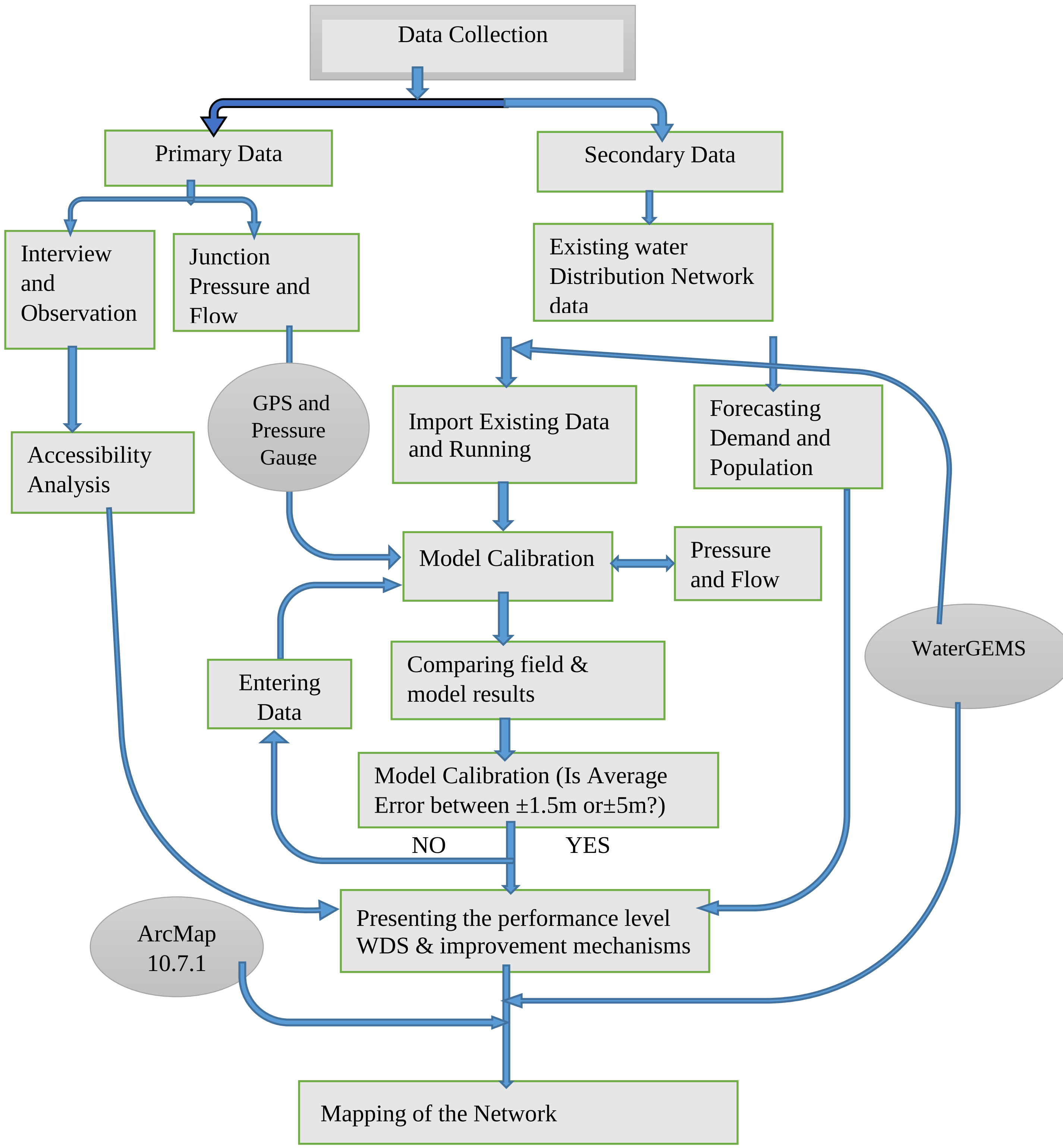


Figure 3-2: Overall framework of the study

4. RESULTS AND DISCUSSIONS

4.1 Per-Capita water demand

It depending on the size and level of development of the town, the type of water delivery system used, the socioeconomic circumstances of the community, and the climatic conditions of the project areas, different demand groups have different per-capita water requirements. The total amount of water needed for various purposes, which are influenced by local environmental factors, population density, and the accessibility of the water supply network in a given townships, is known as the per-capita water demand. According to the service to be utilized and how accessible water supply facilities are, the amount of water needed for various home uses may also change. Asella Water Supply Service Enterprise's bill survey for areas with water connections and survey demands for areas without connections at the time were used to calculate the average per-capita demands, which are displayed in the table below from the annual consumption summary per kebele.

Table 4-1: The last five years' household per capita water demand for Asella Town (L/C/D)

Year (GC)	Water volume Sold(m^3)	Public fountain water prices (birr)	Tariff of water at the public fountain (birr/m^3)	Water volume sold at the public Fountain (m^3)	%age Volume of Commercial and Institutional Consumption (%)
2020	930,057	100,154	3.0	33,384.7	35
2021	1,139,239	93,677.47	3.0	31,225.8	35
2022	1,230,753	100,951.7	3.0	33,650.6	35
2023	1,513,518	76,080.96	3.0	25,360.3	35

Source: (Asella Town Water Supply Service and Field Survey, 2016 report)

4.2 Analysis of yearly water production, consumption, distribution and water loss

4.2.1 Water production

The annual water production initially collected on a monthly basis, then included to assess the water supply. The town of Asella currently gets its water from the Ashebeka river. And there are eight boreholes but, the boreholes are not currently in operation. because they lack a relay system.

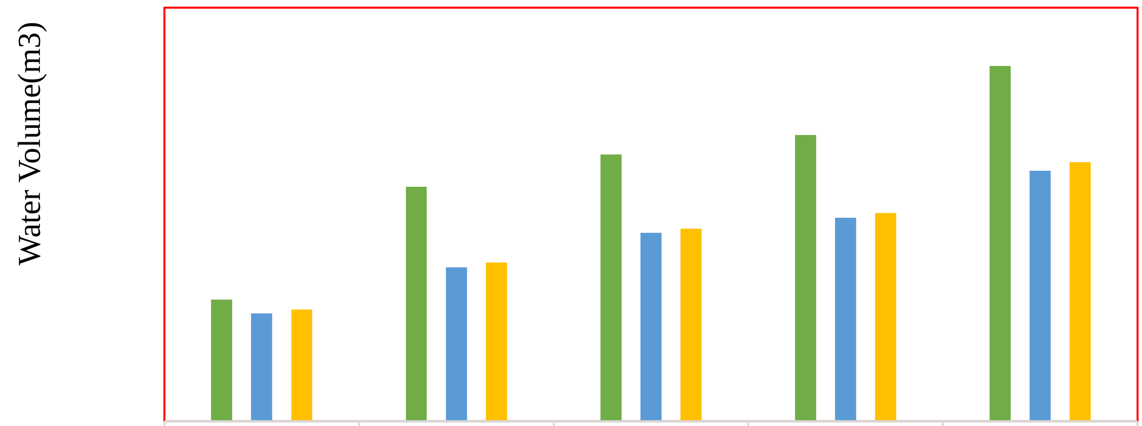
4.2.2 Water consumption

There is a significant shortage of water in Asella town. The majority of households consume very little water, and despite the combined accomplishments of strategies, the demand for water has not been satisfied. And the population of town about 178,473. There will be a severe water deficit in the town, which will cause an increase of demand over available supply. This is because the annual fluctuations in water production and consumption, as well as an unstable production rate, cause the problem. Based on information from the town's water service organization, the charts below give an understanding of the situation.

4.2.3 Water distribution systems

Water from the currently active service reservoirs is transported by gravity to consumers. however, water is pumped, particularly in the area of the treatment plant and on the route to St. Gebriel reservoir. In the distribution system, many pipe types are used at various levels. The town's distribution system has pipes with diameters ranging from 25 mm to 350 mm, and it is 185.3 kilometres long, based on data from the town's water service office. In the town of Asella, the Red Cross service reservoir, the St. Merry service reservoir, and the treatment plant clear water reservoir are connected by the water pipe with the largest diameter.

The current water distribution system in the town only works at a single pressure level. Due to this, there has been an unequal distribution of water, with customers in the town 's expanding areas and higher altitudes suffering low water pressure or no water at all. In addition, there are 103 open taps in the distribution system, which increases water loss and pressure problems. The charts below, which were generated using the data which were generated using data supplied by the town's water service organization, indicate the specifics of water production, consumption and distribution, in a way that is simple for anyone to understand.



	2019	2020	2021	2022	2023
production	735,595	1,416,873	1,613,597	1,731,327	2,147,705
consumption	653,484	930,057	1,139,239	1,230,753	1,513,518
distribution	675,659	960,730	1,165,352	1,260,026	1,566,788

Figure 4-1:Curves showing annual water production, consumption, and distribution

This graph shows that the rate at which water is produced varies annually. The distribution and production curves are almost parallel, indicating that the rate of water loss has been almost constant during the last three years. Different kinds of causes of water loss need to be thoroughly investigated, as well as the reasons why this loss is closely related to water production and consumption.

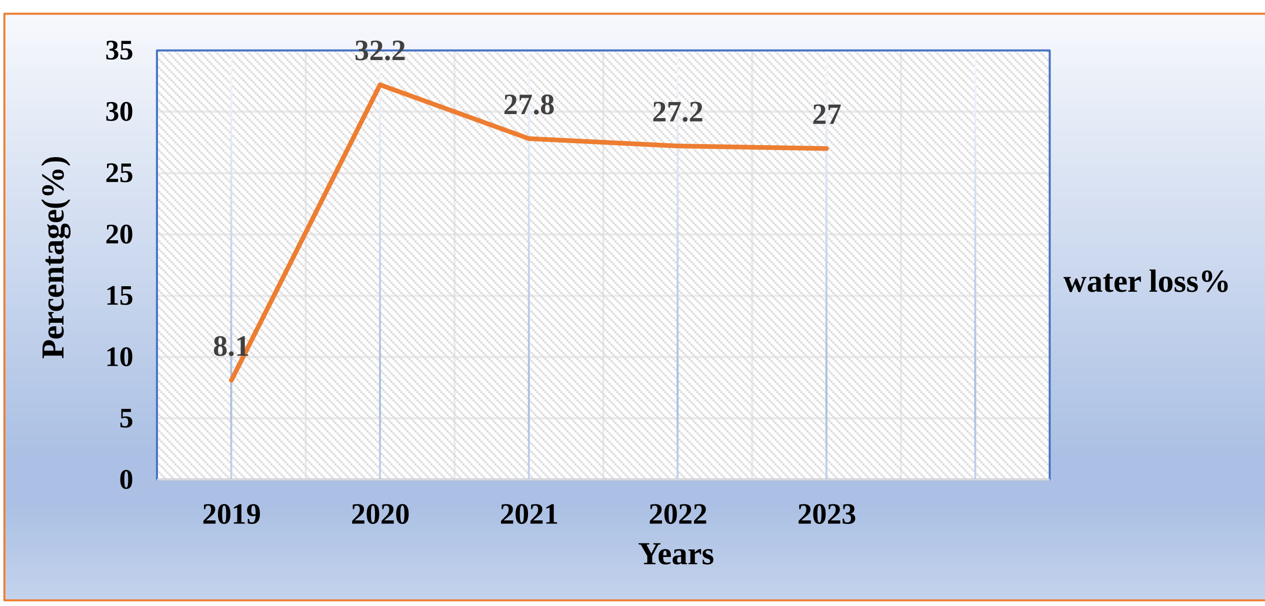


Figure 4-2:Yearly water loss percentage (2019-2023)

Source:(Asella town water supply office 2016 report)

Average Water loss (%) = $\frac{(\text{Total Water produced} - \text{Total Water billed})*100\%}{\text{Total water produced}}$

4.3 Existing Water Storage Reservoirs

Along with the town's main water network, the water reservoirs were gathered. In the town's distribution system, there are eight concrete reservoirs. Using several methods, the water delivery system's reservoir capacity was determined.

St. Merry Reservoir: - This transfer main distributes water from the clean water reservoir of the treatment plant to the St. Merry service reservoir. The main was constructed before 1990EC and it is still giving function. The main has total length of 3300m and nominal size of 350mm. This has maximum capacity to convey up to 95l/s, (Figure, shows that below Appendix E).

St. Gebriel Reservoir: - This pipe alignment currently has a transfer line installed along it. However, because the existing line serves both distribution and transfer purposes, the consultant viewed it as serving as a distribution main line in his study and suggested a separate transfer main be laid parallel to and adjacent to the existing main with an optimal capacity to convey flow of 111.44l/s aimed to serve for both design phases of the project. The main has total length of 1143m and size of 350mm.It giving function still now, (Figure, shows that below Appendix F).

Red Cross Reservoir: - This transfer line starts at the CMTRJ193 and travels along the master plan road until it reaches the Red Cross service reservoir in the pressure zone the main structure was built to carry Phase-I's maximum flow requirement, which is 70.11 l/s, (Figure, shows that below Appendix G).

Table 4-2:Existing Reservoir and Tanks in Asella town water supply system

S. No	Reservoir capacity (m^3)	quantity	Types	Year of implementation (E.C)	Location
1	1000	1	RC	1986-1990	St. Merry Church
2	500	1	RC	1986-1990	Treatment Plant pure water reservoirs
3	400	2	RC	1986-1990	St. Gebriel Church and Red Cross
4	350	1	RC	1962	kebele-14 (Kebro school)
5	200	1	RC	2003	Halila reservoir
6	100	1	RC	1947	Kombolcha River (not operating)
7	10	1	RC	1986-1990	Asella Hospital
8	10	1	RC	1986-1990	Kenenisa Hotel

Generally, for efficient functioning, every reservoir has pipes configurations for inlets, outlets, overflow, and drains. The main problem with this reservoir is related to the manner which the foundation was constructed and poor management practices. Some of them, however, caused damage to water level indicators.

4.4 Hydraulic Network Model Calibration

Comparing the expected and actual performance of a system is an essential step in the calibration process, which makes sure that the model's predictions and the actual system performance are consistent across a wide range of operating conditions. Fifteen data sets from field observations and simulated results were used to calibrate the model. In this research, the fifteen nodes were chosen in accordance with the USEPA water distribution system calibration requirements, which state that a portable pressure gauge should be used to calibrate 2 to 10 percent of all nodes from low pressures to high pressures. Field measurements of pressures at each junction for calibration were performed on home faucets near the junctions. The calibration of the model was performed at peak hour consumption in the morning (6.00–8.30 AM) and minimum hour consumption in the afternoon (2.00–4.00 PM).

The calculated values described under table(b) are within an average error at peak demand of 2.00 m and minimum demand of 1.5 m of pressure simulated and observed values shows that below (Appendix A). The model's calibration is considered appropriate since it satisfies the requirements for pressure calibration and validation (average error 1.5 m to maximum 5 m). According to AWWA (2012) acceptable level of model performance has been shown by the pressure liner regression relationship, which indicated a mean difference error of between ±1.5m and ±5m.The observed values at minimum hour demand and peak hour demand were described in Figures 4-3 and 4-4, respectively.

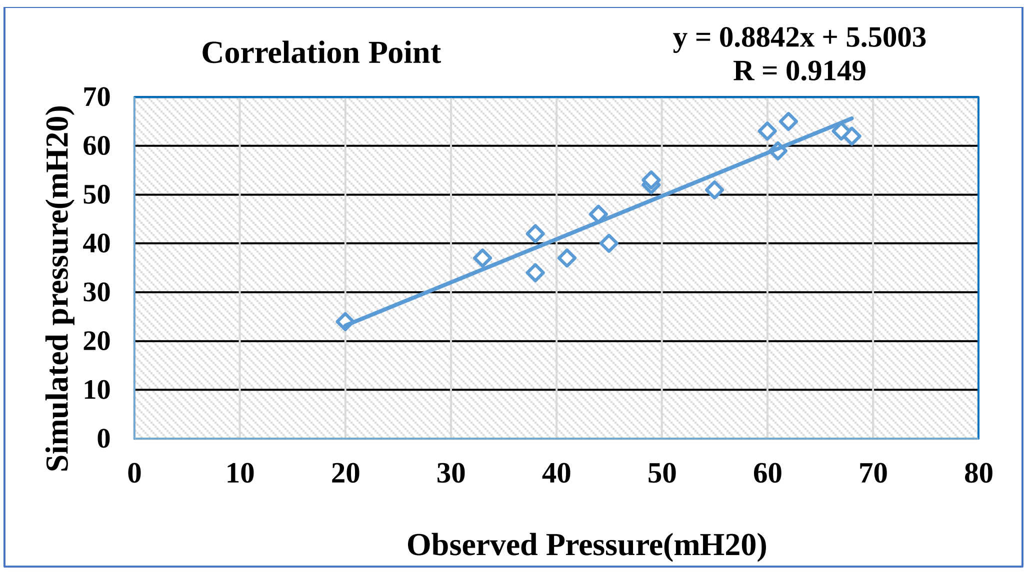


Figure 4-3: Correlation of measured and simulated pressure at the minimum hour consumption

The validation was done by the mentioned formula, and the data presented shows a significant positive correlation for both minimum demand and peak hour demand between the simulated and measured pressure during calibration. The simulated pressure appears to account for 85% and 90% of the variation in the measured pressure, respectively, based on R^2 values of 0.90 and 0.85 for peak hour demand and minimum demand, respectively. This is a good result that suggests the model is correctly representing the system's behaviour which is described in the table A and B (Appendix B). According to AWWA (2012), typically, $R^2 > 50\%$ is considered acceptable for model performance, and the results indicated that the computed and observed values have a significant relationship between them.

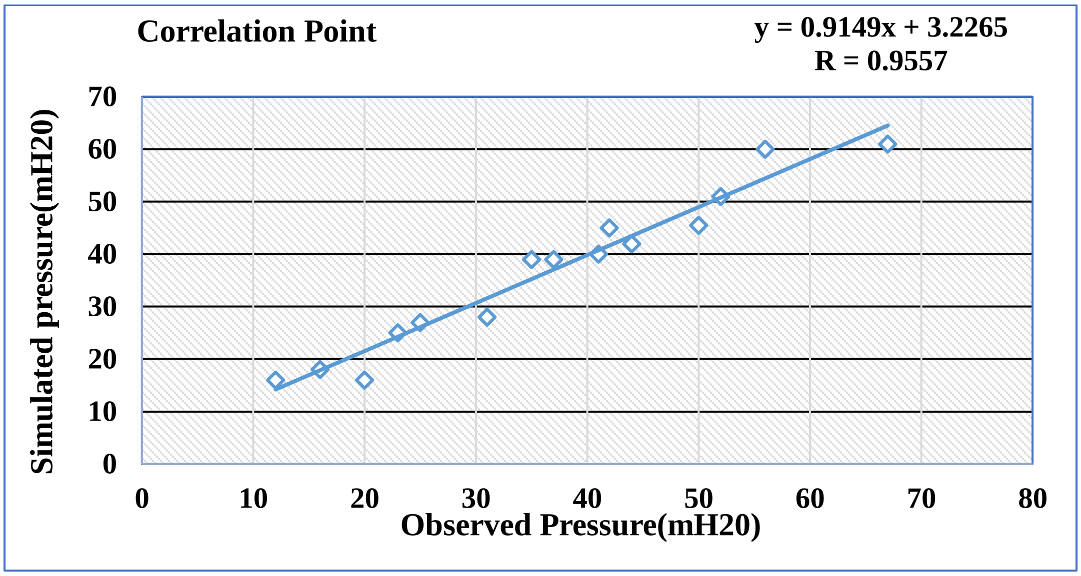


Figure 4-4:Correlation of measured and simulated pressure at peak hour consumption

4.4.1 Pressure analysis

According to the Ministry of Water Resources MOWR (2006), Ethiopia's water supply distribution system network has a working pressure range of 15 to 70 meters. The distribution system's ability to supply water is affected by the water's pressure. Pressure control valves must be installed, a booster station must be constructed, and old pipes must be replaced in order to reach a functional pressure range of 15 meters at the lowest point and 70 meters at the highest point. To avoid leaks and pipe stress the maximum pressure in the main is thought to be 80 meters. The water utility for the town has not established any specific maximum or minimum pressure ranges. As pressure increases but, elevation is decreases. A study was done to assess the water pressure in the Asella Town water distribution system. 986 pipelines and 890 junctions were located during the survey. More details are available in the appendix(A); however, Table 4.3 Summarizes the study's findings for peak consumption.

Table 4-3: The distribution of pressure at peak consumption

Pressure (mH20)	No of Nodes	Percentage
< 10	323	36.30
10-15	219	24.60
15-60	176	19.80
61-70	145	16.29
>70	27	3.03
Total	890	100.00

According to a Bentley WaterGEMS hydraulic analysis, during peaks water demand, 36.30% of the water distribution system's nodes have pressure below the required minimum and 3.03% have pressure above the maximum acceptable pressure. Only 60.69% of the nodes have pressure that is within the acceptable range of 15 to 70 meters, according to this data. The distribution system needs to be improved by 39.33% in order to raise the pressure to within acceptable range.

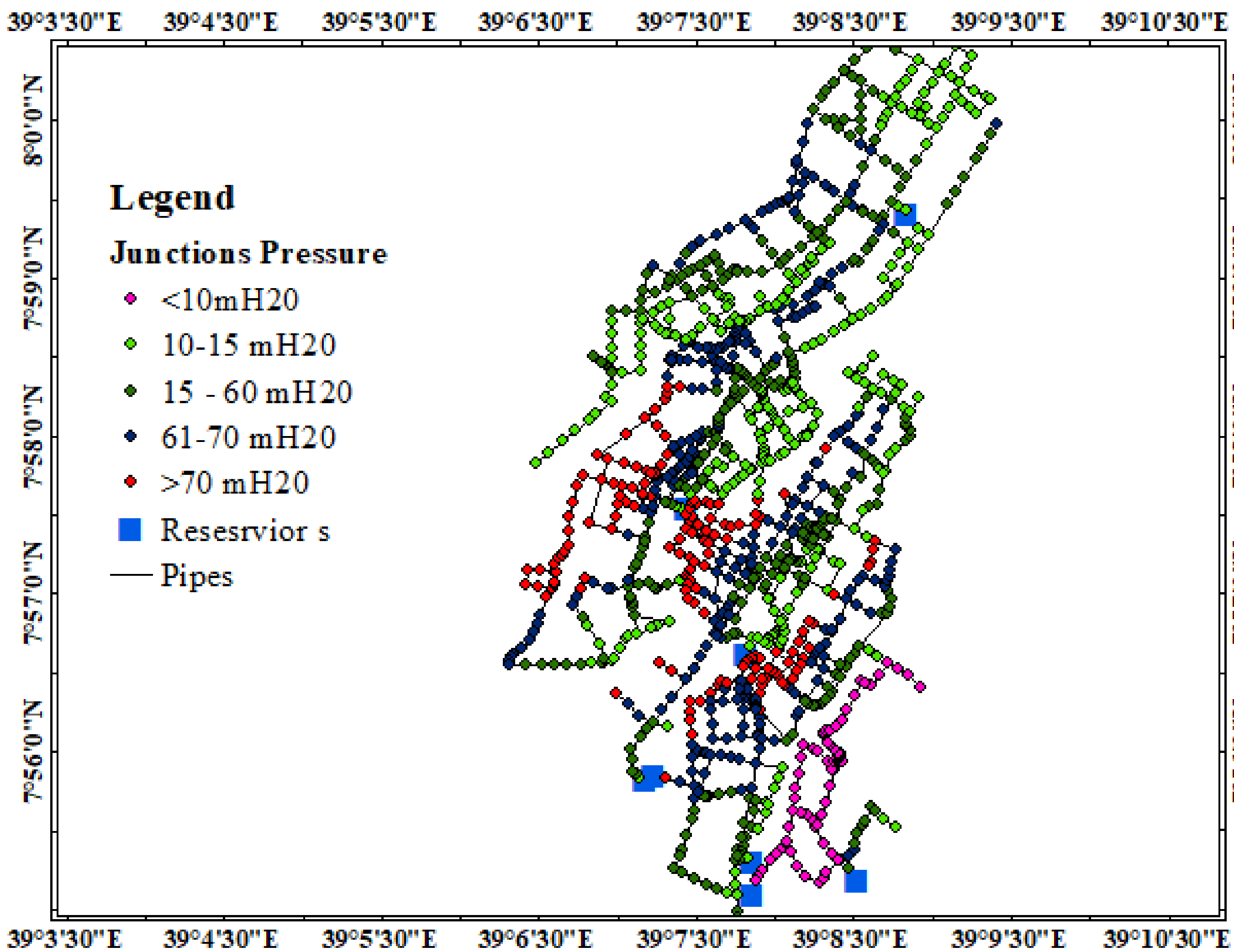


Figure 4-5: Pressure at peak hour consumption

Table 4-4: Pressure distribution at the time of minimum consumption

Pressure (mH20)	**No of Nodes**	**Percentage**
< 10	226	25.39
10-15	319	35.84
15-60	175	19.32
61-70	125	14.04
>70	45	5.05
Total	890	100.00

Most of nodes have unacceptable pressure. only 25.39% of the nodes are functioning at the minimum pressure, while 5.05% of the nodes are exceeding maximum pressure is allowed. Remaining 69.20% of the nodes are working on within an acceptable pressure range, but not at the desired minimal pressure

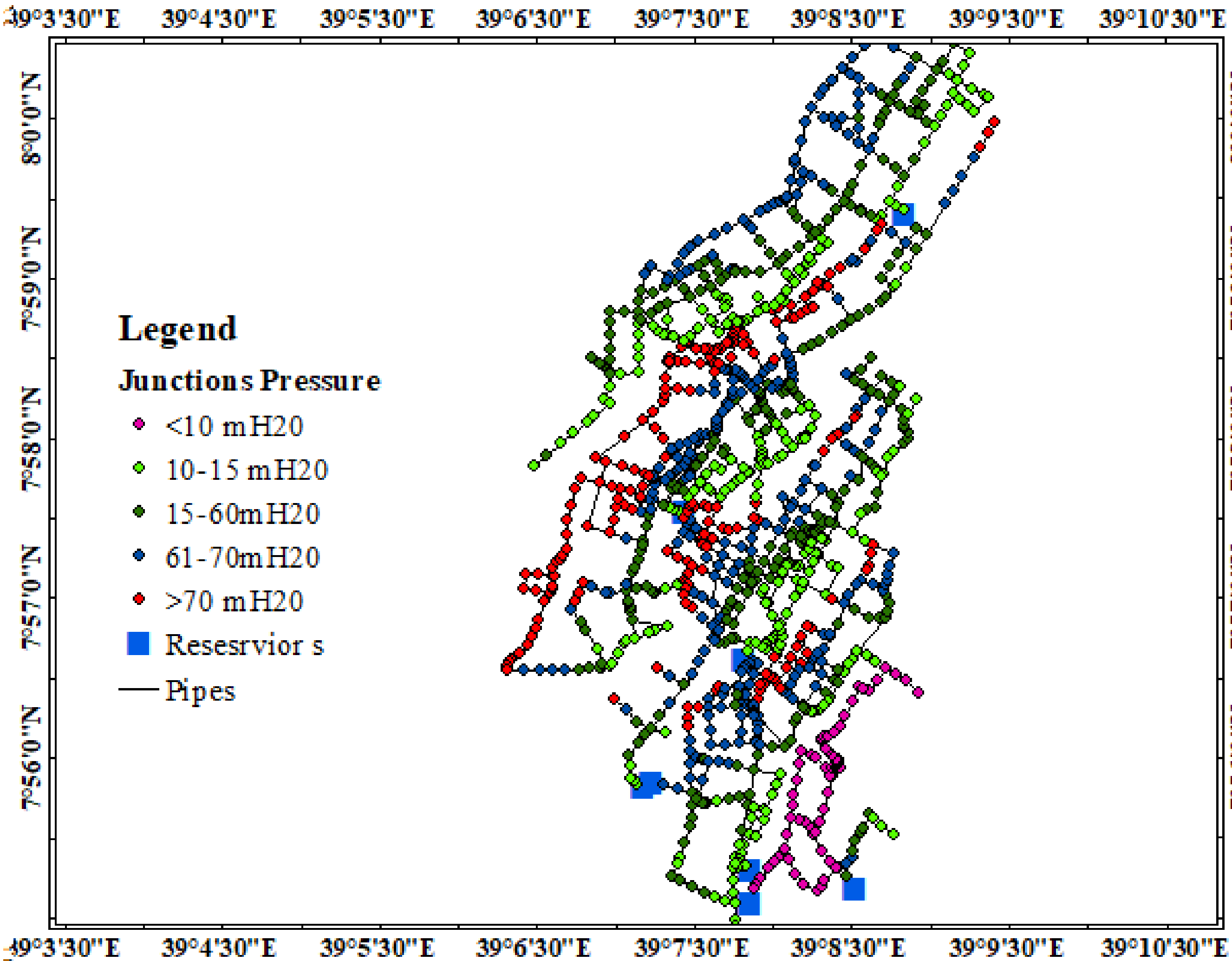


Figure 4-6: Pressure at minimum hour consumption

4.4.2 Velocity analysis

The hydraulic performance of a distribution system for water supplies which is greatly influenced by the water velocity in that system. Less than 0.6 m/s of water flow might cause stagnation, which can encourage the growth of bacteria and garbage in the pipes. More over 2 m/s of water flow might result in head loss and water damage. Due to different consumption patterns throughout the day, water velocity changes. Water velocity is increases during peak consumption and decreases during periods of consumption. The operation and design of a water supply distribution system must ensure that water velocity is maintained within a certain range. This will make it possible to deliver water to customers in a safe and effective manner.

Table 4-5: Velocity of water supply distribution system at peak hour consumption

Velocity (m/s)	No of pipes	Percentage
< 0.6	215	21.80
0.6 -2	243	24.65
2-2.5	344	34.88
>2.5	184	18.66
Total	986	100.00

(As show table 4.5) during in the study's area, during peak water usage hours, water was flowing through 18.66% of the pipes faster than the maximum permissible velocity and 21.80% of the pipes slower than the acceptable minimum velocity. Only 24.65% of the pipes had water flowing at a speed between 0.6 m/s and 2 m/s that was considered acceptable.75.34% of the pipes in the study area had water flowing through them at a rate that was unacceptable by Ethiopia's Urban Water Supply Design Guideline Criteria.

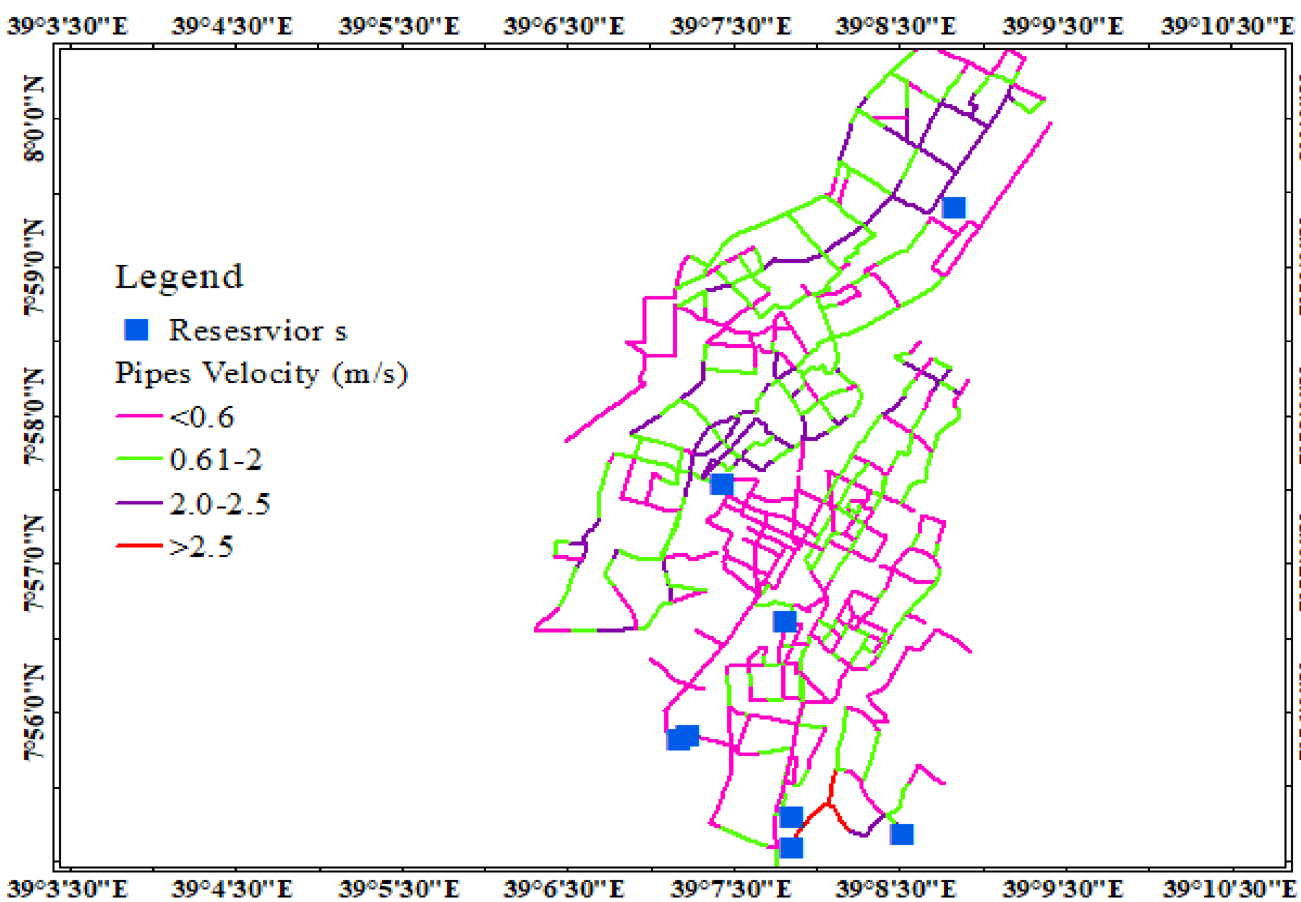


Figure 4-7:Network velocity for water supply distribution during peak hour consumption

during peak water usage times, most of the pipes in the study area were not carrying water at the ideal speed. Some pipes were carrying water too fast, which can damage the pipes and lead to leaks. Other pipes were carrying water too slowly, which can reduce water pressure and make it difficult for people to get enough water.

Table 4-6:Velocity of the water supply distribution system during a period of low consumption

Velocity (m/s)	No of pipes	Percentage
< 0.6	321	32.56
0.6 -2	266	26.98
2-2.5	227	23.02
>2.5	172	17.44
Total	986	100.00

(As show the table-4.6) We can see that 73.02% of the study area's pipes do not operate at acceptable velocities. This indicates that the velocity is either too high or too low. Particularly, 32.56% of the pipes have velocities below the acceptable minimum velocity and 17.44% have velocities higher than the permitted maximum velocity. It is acceptable that just 26.98% of the pipes are moving at a speed between 0.6 and 2 m/s. This is a major issue since it indicates that many of the pipes in this area don't deliver water at the right speed. Low water pressure, water hammer, and even pipe breaks could result from this. It is the most importance to take action to resolve this situation, such as repairing or replacing damaged pipes and installing flow control device.

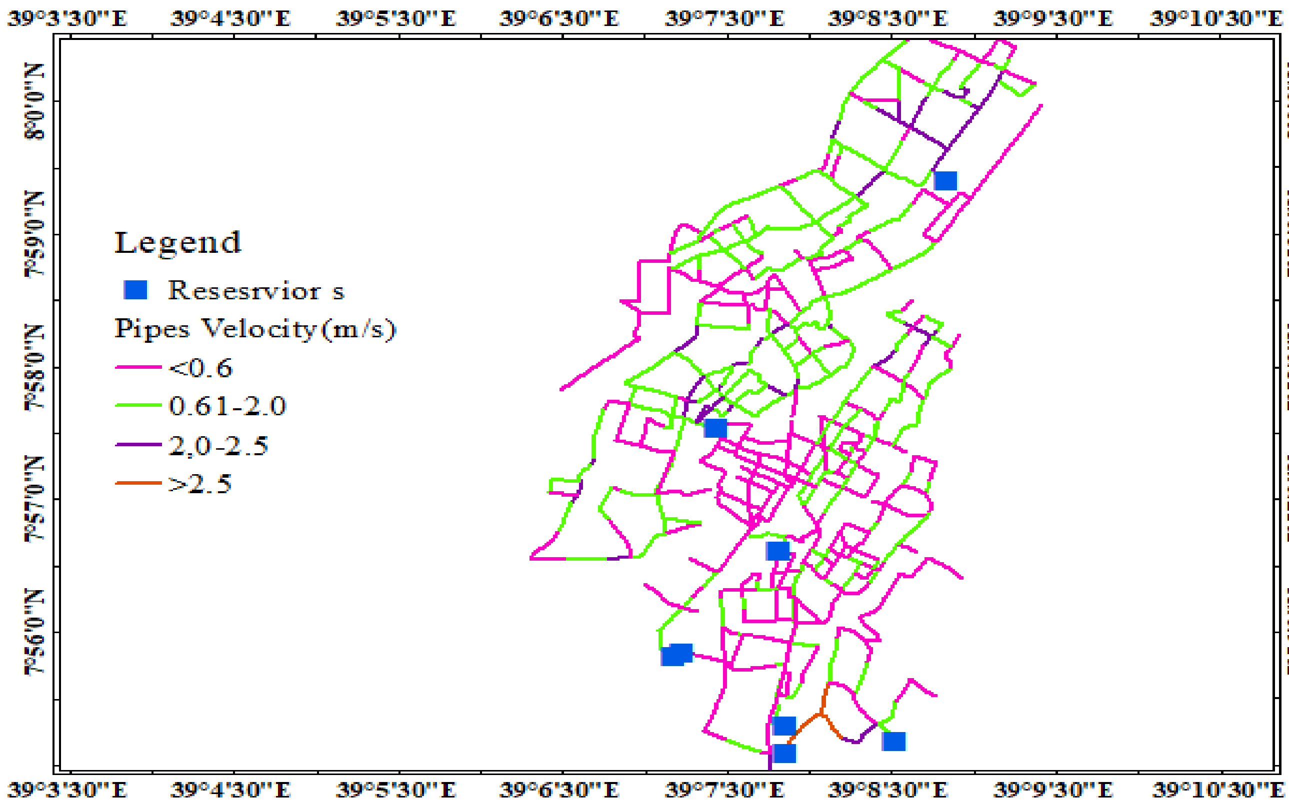


Figure 4-8:The velocity of water supply distribution network during at the time of low consumption

Generally, as indicate Figure (4.7 and 4.8) During a time of low water use, the town's water distribution system's water flow rate was too low. This could result in issues including head loss, pipe breaks, water hammer, stagnant water, sediment build-up in the pipes, and water stagnation. As a result, the water distribution network's flow velocity needs to be managed.

4.4.3 In the town of Asella, the water supply interruption was mostly caused

Lack of water at the source: - This indicates that there was not enough water to satisfy the needs of the settlement at the source.

Poor maintenance: - resulted in issues like leaking pipes and damaged pumps in the water supply system. Pumps that were not operating properly were responsible for pumping water to the town, which limited the amount of water that was available to consumers.

Electricity loss affecting the pumped pressure systems: - When the electricity went out, the pumps that pumped water to the town would stop working, causing a disruption in the water supply.

4.4.4 To improve the water supply in Asella

The following measures are needed: -

Provide a pressure control valve: - This would help to regulate the water pressure in the system and prevent it from getting too high or too low.

Build a boosting station: - This would help to increase the water pressure in the system, which would allow the water to reach more consumers and to reach higher elevations.

Replace the old pipes with new ones that meet the necessary diameter specifications: - This would reduce the amount of water lost to leakage and would also increase the water pressure in the system. By taking these measures, it is possible to ensure that the residents of Asella have a reliable and adequate supply of water.

4.5 Customer satisfaction with the Current Water Supply System

There are 14,664 total customers of the town, as well as commercial, Public, Private, and industrial customers. To determine the level of customer satisfaction with the town's water supply services, a random sample of 374 households was selected.

Table 4-7: Types of customers responded to questionnaires

Customer types	Number of customers	Percentage (%) by category
Private	224	59.89
Industrial	68	18.18
Commercial	54	14.44
Public	28	7.49
Total	374	100.00

Table 4-8:Reponses from customers regarding maintenances

Is the water supply office faster to respond to your maintenance problem?

	Valid	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	99	26.47	26.30	25.30
	No	275	72.72	74.70	74.70
	Total	374	97.86	100	100.00

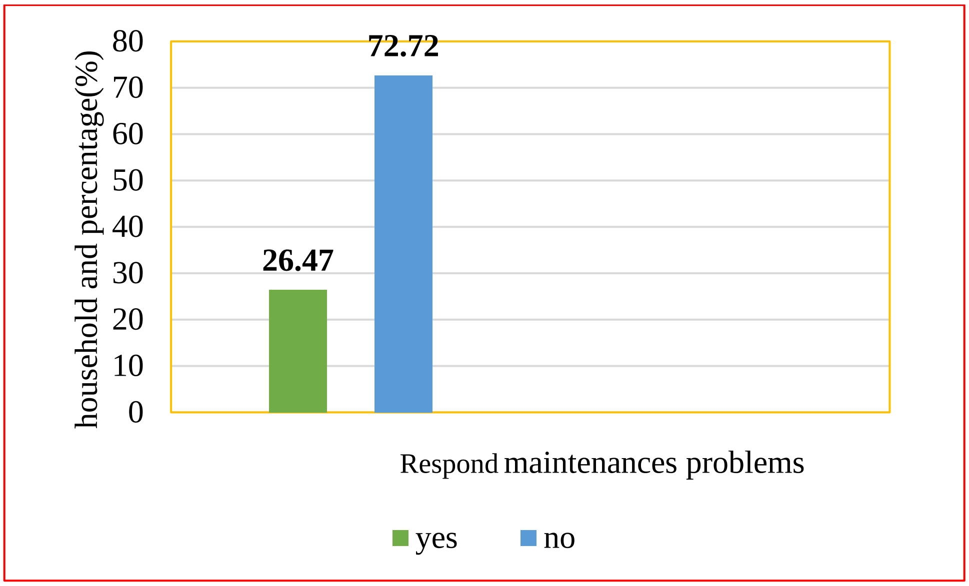


Figure 4-9:Responses from customers regarding maintenances

Out of 374 consumers, 99 (26.47%) responded "yes" to the question about maintenance, while 275 (75.72%) said no. So, water utility office is not responded quickly on maintenance.

Table 4-9:Customer respond to get water in week

How many days a week do you receive water?

		Frequency	Percent	Percent valid	Cumulative percent
Valid	Seven whole days	0	0	0	0
	Five days	62	16.58	16.58	16.58
	Three days	10	27.27	27.28	48.84
	Twice	210	56.15	56.25	100.00
	Total	374	100.00	100.00	100.00

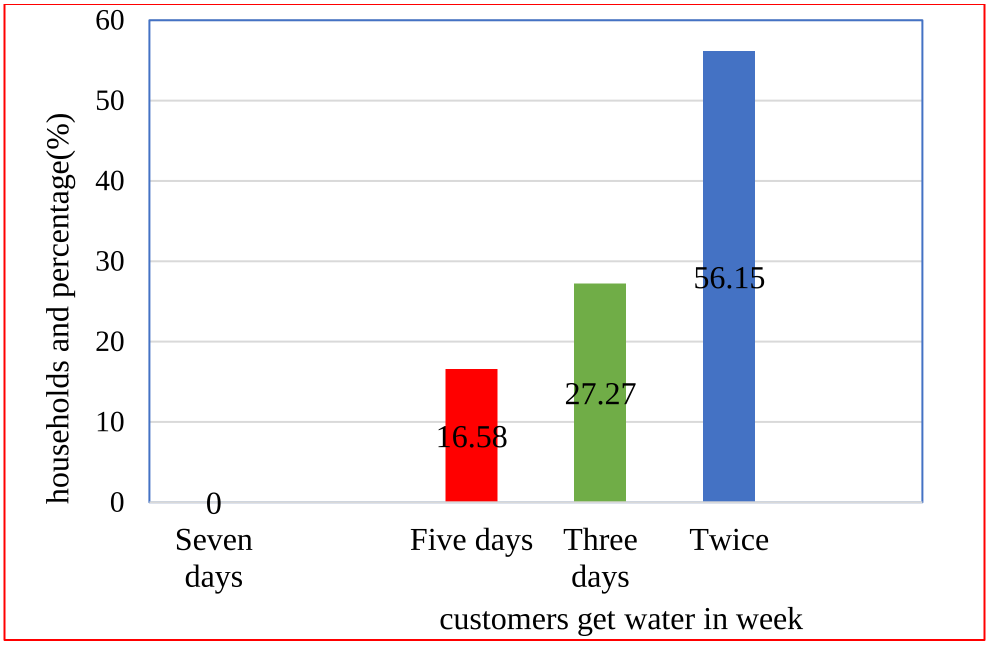


Figure 4-10: responses the customers how many days do you get water per week

In Asella Town, a survey of 374 consumers indicated that 210 households (56.15%) get water twice weekly, 102 people (27.27%) get water three days per week, and 62 people (16.58%) obtain water five days per week. Every day of the week, nobody gets water. Asella Town depends on a few bore holes for its temporary water supply. Due to system damage or power failures, the water supply is frequently stopped. In Asella Town, the majority of households get water a few times per week, and the water supply is unstable. Given that having access to clean water is crucial for maintaining human health and wellbeing, this is a serious problem.

Table 4-10: Customers responses on level of satisfactions

What kind of satisfied are you with the water supply delivery?

		Frequency	Percent	Percent valid	Cumulative Percent
Valid	Very satisfied	0	0	0	0
	Satisfied	62	16.58	16.58	16.58
	Fairly satisfied	82	21.93	21.94	38.52
	Not satisfied	230	61.49	61.50	100.00
	Total	374	100.00	100.00	100.00

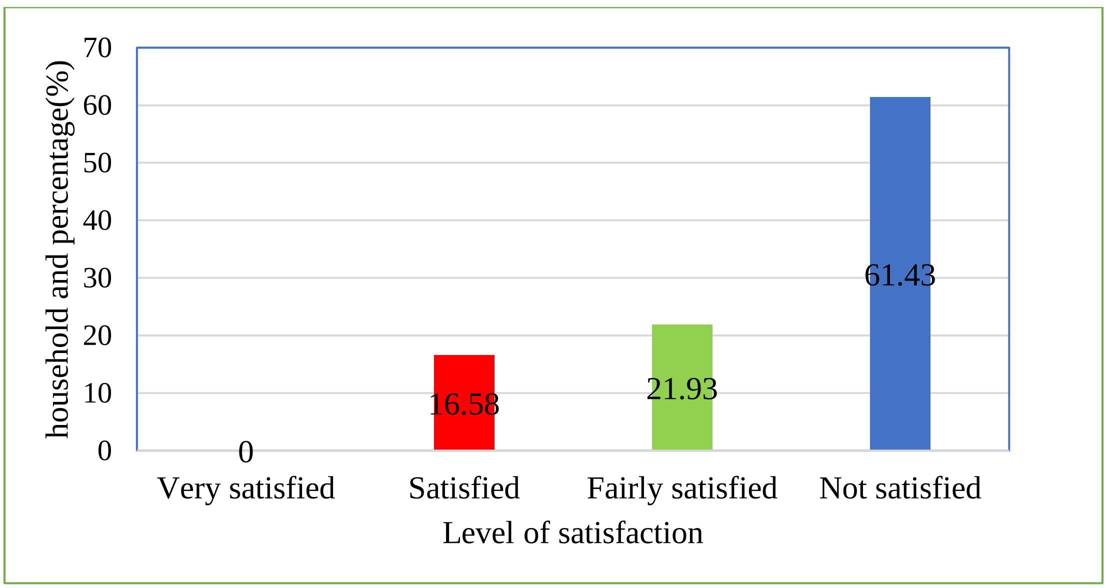


Figure 4-11: Customers satisfaction with the water supply service

In a survey of 374 respondents, 62 (16.58%) said they were satisfied with the water supply service, 82 (21.93%) said they were fairly satisfied, and 230 (61.49%) indicated they were not satisfied. Nobody said they were very satisfied in responded.

Table 4-11: Consumer response regarding water consumption

What amount of water is used for litres each day?

	Frequency	Percent	Percent valid	Cumulative Percent
Less than 50L	65	17.38	17.38	17.38
50 -100L	92	24.59	24.50	41.88
100- 500L	112	29.95	29.30	71.18
Greater than 500L	105	28.07	29.17	100.00
Total	374			

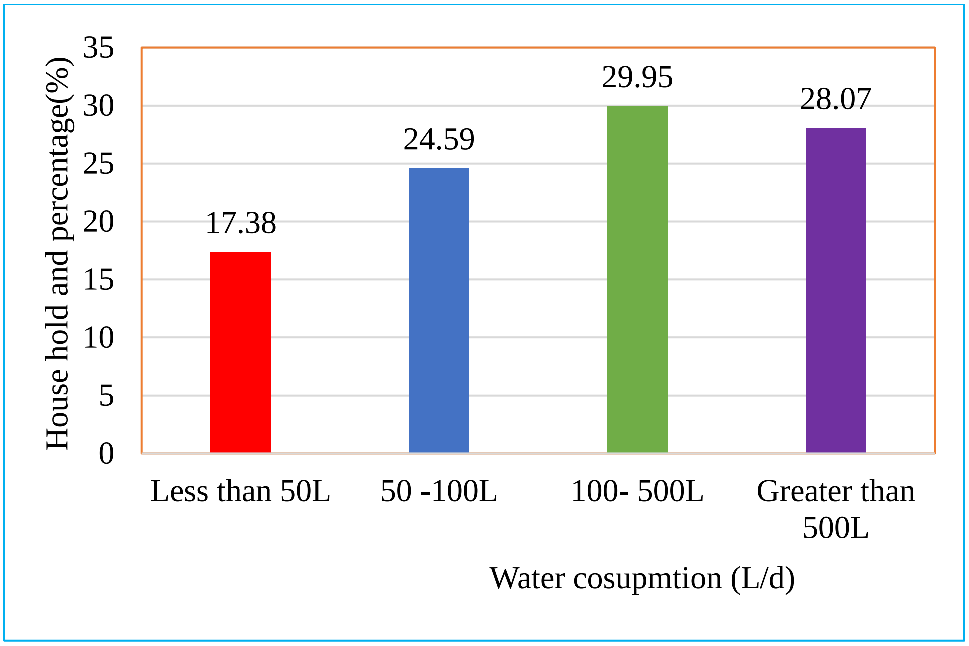


Figure 4-12:Customers response to every day water consumption

The majority of respondents used water. The most common daily water uses 92 or24.59 %was between 50 and 100 litres, 112 or 29.95% using water from 100 to 500 litres. A smaller percentage of respondent’s daily water use 65 or 17 38% less than 50 litres and, the remaining,105 or 28.07% more than 500 litres. This means that most households do not have access to an improved water supply.

Table 4-12: Responses from customers regarding the distance to fetch water

The distance to get water, in your opinion, is how many meters?

		Frequency	Percent	Percent Valid	Cumulative Percent
Valid	<10m	132	35.29	35.30	35.30
	10- 100m	91	24.33	24.34	59.64
	100m- 1km	82	21.93	21.94	81.57
	More than 1km	69	18.45	18.45	100.00
	Total	374		100.00	

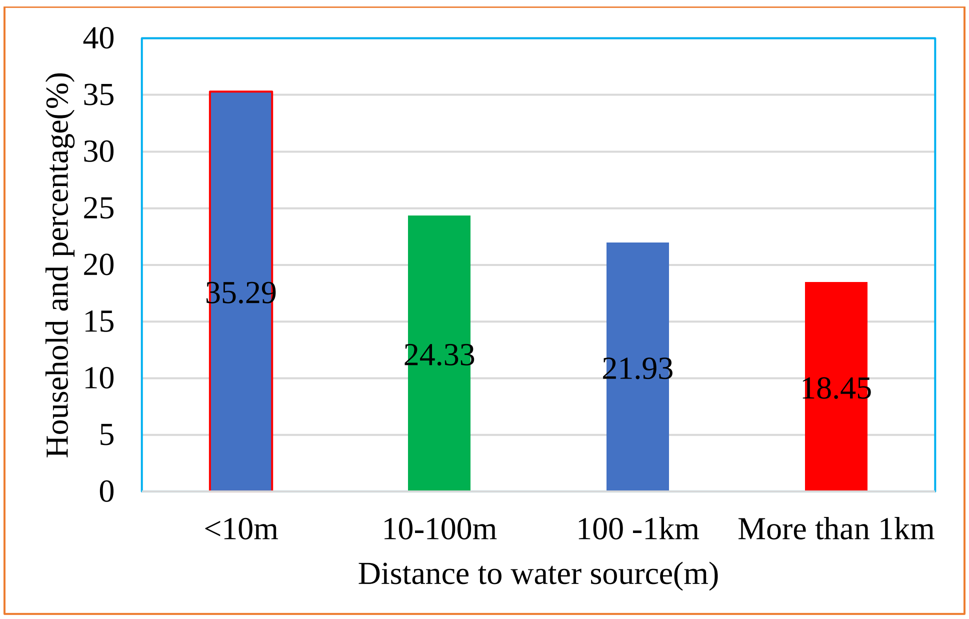


Figure 4-13:Customers response regarding to the distance to fetch water

The majority of respondents,91or (24.33%) said that their home was between 10 and 100 meters from their main supply of drinking water. 132 or (35.29%) said their primary source of drinking water was less than 10meters distant. The remaining 82 households or (21.93%)) were located, between 100 meters and 1kilometer from their main source of drinking water. and 69 or (18.45% of the respondents have been found to be more than 1 km from the primary drinking water source. These last-mentioned households have a very high risk of inadequate sanitation and water scarcity.

Table 4-13:Customer respondents time required to fetch water

What is the time required to get water in minutes?

	Valid	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	<5minutes	168	44.92	44.92	44.92
	5-30 minutes	114	30.48	30.48	75.40
	more than 30 minutes	92	24.59	24.50	100.00
	Total	374	100.00	100.00	

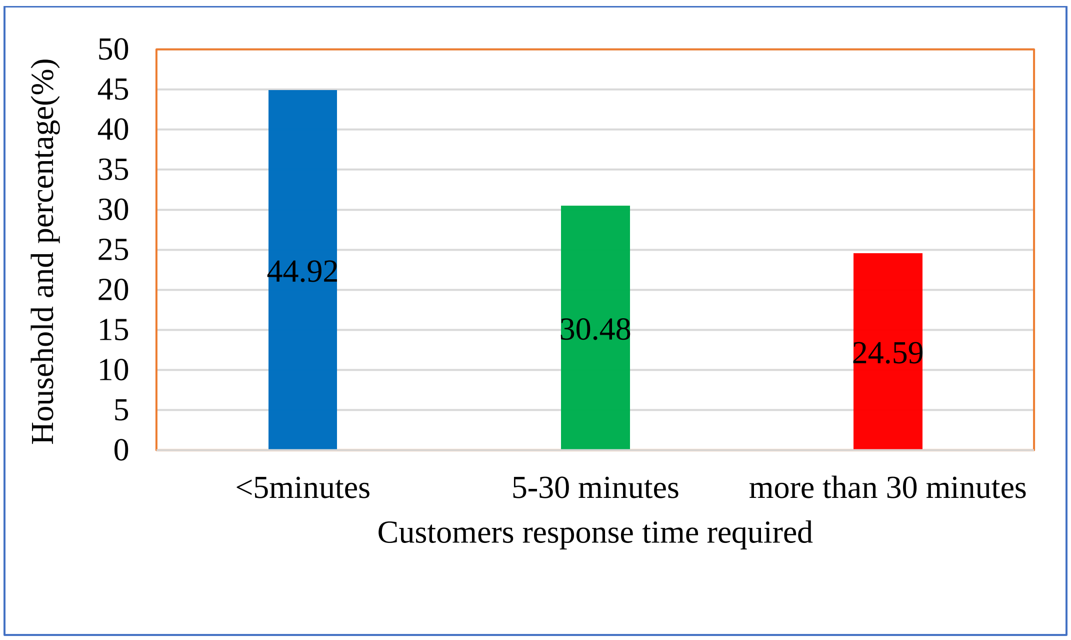


Figure 4-14:Customers response time required to get water

According to a study, 168 (44.92%) homes waited less than 5 minutes to collect water, compared to 114 households or (30.48%) that waited between 5 and 30 minutes and 92 (24.59%) households who waited more than 30 minutes. These findings imply that the town's water supply does not adequately serve its citizens. Customers must wait a long time to get their water, and the quality is poor. To give locals access to dependable and safe water, the water utility office needs to improve its operations.

4.6 An Assessment of the Present Problems with Water Supply

The current water delivery system's state is assessed from both a technical and socioeconomic perspective. In order to develop potential short- and long-term measures to address the problems currently noticed, key problems were also identified. The following is a concise description of the Asella town's current water supply situation.

a) **Problem of access to water points: -** The inhabitants living particularly at the town peripheral and elevated areas are facing a serious water shortage problem. Especially people residing very close to service reservoir, expansion areas of the town in all directions and town part located at relatively higher altitudes compared to the existing service reservoir sites are getting water at a high rate from vendors than the normal water tariff set by the utility. Even the distribution system in the town is not balanced resulting in some areas of the town with continuous supply, (Figure, show that below Appendix H).

b) **Time wastage: -** The People frequently spend a large amount of time waiting in lines at newly constructed public fountains. Same way without construction of public fountains, the water service enterprise of the town erect stand pipes fitted with four to six faucets on mains with water to reach his customers, (Figure, show that below Appendix I).

4.7 Assessment of maintenance and operation

The water supplies for the Asella town were operational by 2015. There is a treatment facility among them, along with a 350 m3 service reservoir at kebele-14 (Kebro), a 500 m3 service reservoir at the recently destroyed town building, one break pressure chamber at the club house (ARDU Residence), and an undetermined length of distributing pipe networks that are still in use. The town water service administration office was established in 1969EC as a change to the previous administration system under the municipality office. Its primary functions and duties involve maintaining attention on the town water distribution system's supply, repairs, expansion, improvement, and general coordination.

The town water supply system is supplied, maintained, expanded, studied for new schemes, and generally coordinated by the town water service administration office, which was formed in 1969EC. Project operations began in 1990EC with the completion and activation of the new system derived from the Ashebeka River. The EWWCA installed water supply infrastructure, such as two Ashebeka River intake structures with a combined capacity of 75% gravity and 25% pumping. Additionally, 34.2 km of transmission and falling mains were installed from the Ashebeka River to the Asella treatment facility, and up to distribution network of around 36.53 kilometers.

In Asella, the water treatment plant and reservoir are not adequate staffing and managed. Due to this, the town is experiencing water shortages and loss. The intake is protected by an illiterate utility guard, and there are no permanent operators residing on the site. The reservoir tanks have neither a guard nor an operator present. The water utility lacks the equipment, components, or regulations required to manage leaks effectively. The town is consequently suffered with a water deficit. Components are only inspected when they break or are damaged, indicating that the entire maintenance method is insufficient.

4.7.1 Observed problems with operations and maintenance

The challenges of operating and maintaining the Asella town water supply system. The first problem is that no publicly available maps shows that the location of sources, reservoirs, pumping stations, distribution network pipes' sizes, lengths, and ages, and the routes and valves of transmission pipes, as well as the locations of fire hydrants and gate valves. Because of this, it is challenging to identify and address systemic problems far away. The absence of district water meters or flow meters at the main pipelines of the distribution system presents another challenge. Because of this, it is challenging to estimate the amount of leakage and locate the source of excessive leakage so that corrective action can be taken. The components of the water supply system aren't assessed or maintained as part of a planned or regular schedule.

This implies that they are not routinely inspected or maintained, which could result in issues like leaks, breakdowns, and contamination. Most sources don't maintain a permanent notebook or book for protecting of water production. The information is instead recorded on a piece of paper. This indicates that the data is not organized or stored in an appropriate way, which increases the risk of damage or loss. The existing operation and maintenance problems of around Ashebeka river is briefly described as follows: -

a) The supply system is frequently interrupted due to falling main breaks, as a result of improper laying across gullies and erosion suspected areas and illegal residents of peasant associations in Digalu Tijo woreda through which the main will pass and convey water from Ashebeka river to the town treatment plant, (Figure, show that below Appendix J).

b) **Reduction in yield of water source**: A number of factors, including changes in land use and cover around the spring eyes that form rivers and throughout the entire catchment, as well as the use of the Ashebeka River for traditional irrigation practices upstream of the gravity main intake site, have been linked to a regular reduction in the yield of the river, especially during dry seasons, (Figure, show that below Appendix K).

c) **Absence of Source Protection**: The current pattern of farming activities along the whole upstream catchment of the Ashebeka River is likely to result in contamination from agrochemicals and reduce river discharge. In a similar vein, eucalyptus vegetation will have a negative impact and significantly lower river discharge by destroying all-natural vegetation in the river catchment upstream of the intake site.

d) **Timely repairs are not made, reportedly: -** due to unavailability of appropriate maintenance equipment and capacity within the town water service and also integrated management system with the Digalu & Tijo woreda sector offices. As a result of this different scale social impacts have been raised so far falling the falling and pumped main from Ashebeka river

4.7.2 Summary of operation and maintenance

To ensure the water supply system's correct operation, it's important to: -To make it simple to check for leaks and other issues, the water pipelines that transport water from boreholes to reservoirs are placed alongside roads. The amount of water produced at the sources and pumping stations should be recorded. Respond quickly to maintenance requests from customers. Any damaged water meters should be fixed or replaced.

To find leaks and damage, perform routine checks on all components of the water supply system, including the sources, reservoirs, transmission pipes, and distribution pipes. regular inspections and maintenance are necessary to ensure the water supply system's safety and dependability. Following the suggestions made earlier, water utilities can help ensure safety water all times. It is important to check water pipelines for damage following severe storms or construction near or on pipelines. All of the town's water sources were in good condition during the research period, despite the fact that several of them are not currently in use. The water utility office needs to maintain a current map of the town's water distribution system. The map has to accurately show the locations of all valves, flow meters, fire hydrants, reservoirs, pumping stations, and water sources, as well as the design, measurements, and lengths of all distribution and transmission pipes.

All staff members involved in the operation as well as maintenance of the water delivery system must get regular training, according to water providers. Mechanics, plumbers, and other staff members are examples of skilled labour in pumping stations. Additionally, it's crucial to store the manufacturer's instructions for operating and maintaining electrical and mechanical equipment in a place that is easy to get to. Data on water production and use should also be gathered and organized both digitally and physically so that it is always available.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main goal of this study was to assess the performance and improvement methods as well as the accessibility of the town's water distribution system. To achieve this research purpose, population and water demand were forecasted to check whether or not the existing source satisfied the current and future demand. The hydraulic performance of the town's water distribution system and the degree of customer satisfaction were also evaluated. The water distribution system failures are the cause for the water shortages in Asella town. This study also, assessed the hydraulic performance of the water supply distribution system in Asella town by using Bentley Water GEMS V8i software. During in the study's area, during peak water usage hours, water was flowing through 18.66% of the pipes faster than the maximum permissible velocity and 21.80% of the pipes slower than the acceptable minimum velocity.

Only 24.65% of the pipes had water flowing at a speed between 0.6 m/s and 2 m/s that was considered acceptable.75.34% of the pipes in the study area had water flowing through it at a rate that was unacceptable by Ethiopia's Urban Water Supply Design Guideline Criteria.During peak water usage times, most of the pipes in the study area were not carrying water at the ideal speed. Some pipes were carrying water too fast, which can damage the pipes and lead to leaks. Other pipes were carrying water too slowly, which can reduce water pressure and make it difficult for people to get enough water. That can see that 73.02% of the study area's pipes do not operate at acceptable velocities. This indicates that the velocity is either too high or too low.

The town's water utility's poor management is the major issue. Water shortages are currently caused by the failure of many boreholes. Additionally, due to a lack of maintenance, many of the pipelines and valves are not working properly. During times of low consumption, the water distribution network frequently occurring pipe breaks and bursts, leading to significant water loss, particularly in high pressure zones. A lot of households in crowded and high elevation areas did not have continuous water service during times with high consumption. In addition, the network's water pressure did not meet the maximum and minimum design standards established by the Ministry of Water, Energy, and Irrigation (MOWIE). Water losses are increasing as a result of improper operation and maintenance of the town's supply system, which makes it challenging to meet demand for water. This additionally shows the ineffective management of the system.

The majority of customers are not satisfied with the water delivery service's quality, water pressure, availability, and maintenance response. Generally, the town's the main issue is the water supply system's poor performance. The demand for water and the supply that is not balance. The results, show that the majority of the customers are should be satisfied with the existing water supply service since the satisfaction level of Asella Town.

5.2 Recommendations

The Asella town water supply system might be improved in the areas of water loss, water quantity, customer satisfaction, operation, and maintenance with the support of the suggestions listed below.

- The town's water pipe system needs to be operated and maintained according to established, regular methods if it is going to function better overall.
- This involves performing deliberately done and regular checks for leakage and other damage on all water supply system parts, including reservoirs, transmission and distribution pipelines, collection chambers, and pump structures.
- The water provider should respond to maintenance requests immediately away to prevent water loss and consumer complaints. In order to understand the needs and problems of their customers, they should also often communicate with them. The water provider should also carry out frequent surveys to assess consumer satisfaction and identify areas for improvements.
- Water utilities should keep a current map of the water supply system that details all of its parts, including valves, flow meters, fire hydrants, reservoirs, pumping stations, and water sources, as well as the widths and lengths of the system's distribution and transmission pipes. The water utility office should have access to this map so that workers can properly maintain and operate the system.
- In order to minimize the high pressures and reduce leakage or water loss in the system, the proposed improvement methods for the existing problems will be solved if the water utility office implements them. So that, the water utility authorities need to be vigilant and present dimensions on water loss management strategies.

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APPENDIXES

APPENDIX A: Sample Nodes Selected for Calibration and Validation

a) Sample nodes and corresponding field test site location

Software simulation				Field Measurement			Head loss Between points(m)
Junction ID	X(m)	Y(m)	Elevation (m)	X(m)	Y(m)	Elevation (m)	
J-95	514,562.37	878,213.17	2,453.09	514,562.27	878,213.57	2,453.01	0.08
J-47	514,236.39	874,562.10	2,534.73	514,236.29	874,562.20	2,534.81	-0.08
J-30	514,130.49	875,268.31	2,536.74	514,130.00	875,268.78	2,535.67	1.07
J-103	514,789.26	878,460.59	2,438.10	514,789.26	878,462.20	2,437.99	0.11
J-116	515,272.80	879,479.12	2,416.77	515,272.30	879,479.79	2,415.63	1.14
J-129	514,817.12	879,052.23	2,425.34	514,817.72	879,052.93	2,426. 43	-1.09
J-206	514,821.96	879,061.59	2,425.02	514,821.16	879,061.11	2,425.11	-0.09
J-271	515,463.98	877,940.28	2,508.15	515,463.18	877,982.00	2,507.11	1.04
J-493	513,228.91	879,594.21	2,335.09	513,228.11	879,595.00	2,337.09	-2.00
J-617	513,721.38	876,131.52	2,510.84	513,721.78	876,131.12	2,511.49	-0.65
J-731	516,495.74	884,254.78	2,232.75	516,495.34	884,259.18	2,231.33	1.42
J-760	515,954.12	882,455.74	2,301.75	515,954.92	882,455.89	2,301.10	0.65
J-1176	515,749.52	880,399.63	2,397.77	515,749.70	880,391.02	2,398.02	-0.25
J-1144	514,453.60	878,924.22	2,414.02	514,453.00	878,934.89	2,415.02	-1.00
J-1328	512,273.86	877,948.56	2,304.10	512,274.86	877,948.06	2,303.00	1.10

b) Simulated and Observed pressure run at first time

No of sample	Junction ID	Measurement Time	Computed Pressure (mH20)	Measured Pressure (mH20)	Error (m)
1	J-95	At minimum consumption hour (2.00 -4.00 PM)	61	59	2.00
2	J-47		20	24	-4.00
3	J-30		38	34	4.00
4	J-103		49	52	-3.00
5	J-116		60	63	-3.00
6	J-129		55	51	4.00
7	J-206		68	62	6.00
8	J-271		33	37	-4.00
9	J-493		38	42	-4.00
10	J-617		49	53	-4.00
11	J-731		41	37	4.00
12	J-760		45	40	5.00
13	J-1176		62	65	-3.00
14	J-1144		44	46	-2.00
15	J-1328		67	63	4.00
Average Error					**2.00**
1	J-95	At Peak Hour Consumption (6.00 -8.30 AM)	12	16	-4.00
2	J-47		16	18	-2.00
3	J-30		56	60	-4.00
4	J-103		20	16	4.00
5	J-116		50	45.5	4.50
6	J-129		52	51	1.00
7	J-206		44	42	2.00
8	J-271		67	61	6.00
9	J-493		37	39	-2.00
10	J-617		35	39	-4.00
11	J-731		41	40	1.00
12	J-760		42	45	-3.00
13	J-1176		23	25	-2.00
14	J-1144		25	27	-2.00
14	J-1328		31	28	3.00
Average Error					**1.50**

APPENDIX B: Model Validation Using Regression Method

A) Regression coefficient at minimum consumption hour

$$R = \frac{\sum(X-X^{-})(Y-Y^{-})}{\sqrt{\sum(X-X^{-})^2} * \sqrt{\sum(Y-Y^{-})^2}}$$

Junctions	Computed Pressure(Y)	Observed Pressure(X)	Y-X	$Y-Y^{-}$	$X-X^{-}$	, $(Y-Y^{-})^2$	$(X-X^{-})^2$	$(X-X^{-}) * (Y-Y^{-})$	$(X-X^{-})^2 * (Y-Y^{-})^2$
AsJ-95	61	59	2	12.33	10.47	152.11	109.55	129.09	16663.94
AsJ-47	20	24	-4	-28.67	-24.53	821.78	601.88	703.29	494615.26
AsJ-30	38	34	4	-10.67	-14.53	113.78	211.22	155.02	24031.89
AsJ-103	49	52	-3	0.33	3.47	0.11	12.02	1.16	1.34
AsJ116	60	63	-3	11.33	14.47	128.44	209.28	163.96	26881.42
AsJ129	55	51	4	6.33	2.47	40.11	6.08	15.62	244.05
AsJ206	68	62	6	19.33	13.47	373.78	181.35	260.36	67785.02
AsJ271	33	37	-4	-15.67	-11.53	245.44	133.02	180.69	32648.47
AsJ493	38	42	-4	-10.67	-6.53	113.78	42.68	69.69	4856.54
AsJ617	49	53	-4	0.33	4.47	0.11	19.95	1.49	2.22
AsJ731	41	37	4	-7.67	-11.53	58.78	133.02	88.42	7818.49
AsJ760	45	40	5	-3.67	-8.53	13.44	72.82	31.29	978.99
AsJ1176	62	65	-3	13.33	16.47	177.78	271.15	219.56	48204.64
AsJ1144	44	46	-2	-4.67	-2.53	21.78	6.42	11.82	139.76
AsJ1328	67	63	4	18.33	14.47	336.11	209.28	265.22	70342.83
Total	**730**	**728**	**2**			**2597.33**	**2219.73**	**2296.67**	**795214.87**
Mean	48.67	48.53							

R^2=0.95

B) Regression coefficient at peak hour consumption

Junctions	Computed Pressure(Y)	Observed Pressure(X)	Y-X	$Y-Y^{-}$	$X-X^{-}$	, $(Y-Y^{-})^2$	$(X-X^{-})^2$	$(X-X^{-}) * (Y-Y^{-})$	$(X-X^{-})^2 * (Y-Y^{-})^2$
AsJ-95	12	16	-4	-24.73	-20.83	611.74	434.03	515.28	265511.19
AsJ-47	16	18	-2	-20.73	-18.83	429.87	354.69	390.48	152472.89
AsJ-30	56	60	-4	19.27	23.17	371.20	536.69	446.34	199223.36
AsJ-103	20	16	4	-16.73	-20.83	280.00	434.03	348.61	121529.71
AsJ116	50	45.5	4.5	13.27	8.67	176.00	75.11	114.98	13219.89
AsJ129	52	51	1	15.27	14.17	233.07	200.69	216.28	46776.08
AsJ206	44	42	2	7.27	5.17	52.80	26.69	37.54	1409.59
AsJ271	67	61	6	30.27	24.17	916.07	584.03	731.44	535010.98
AsJ493	37	39	-2	0.27	2.17	0.07	4.69	0.58	0.33
AsJ617	35	39	-4	-1.73	2.17	3.00	4.69	-3.76	14.10
AsJ731	41	40	1	4.27	3.17	18.20	10.03	13.51	182.55
AsJ760	42	45	-3	5.27	8.17	27.74	66.69	43.01	1849.96
AsJ1176	23	25	-2	-13.73	-11.83	188.60	140.03	162.51	26409.86
AsJ1144	25	27	-2	-11.73	-9.83	137.67	96.69	115.38	13312.03
AsJ1328	31	28	3	-5.73	-8.83	32.87	78.03	50.64	2564.86
Total	**551**	**552.5**	**-1.5**			**3478.93**	**3046.83**	**3182.83**	**1379487.38**
Mean	36.73	36.83			R^2 =0.98				

APPENDIX C: Pressure-output Water GEMS.

Label	Length (m)	Dimeter (mm)	Velocity (m/s)	Discharge (l/s)	Haze Williams (C)	Material	Starting Node	Ending Node
P-388	45.11	80	0.46	2.32	100	DCI	J604	J603
P-389	11.89	80	0.46	2.32	100	DCI	J603	J602
P-387	64.01	80	0.46	2.32	100	DCI	J605	J604
P-348	17.68	100	0.5	3.91	100	DCI	J1427	J1428
P-349	89.31	100	0.5	3.91	100	DCI	J1428	J1429
P-393	121.31	80	0.46	2.32	100	DCI	J599	J598
P-394	140.82	80	0.46	2.32	100	DCI	J598	III_Ar_2
P-392	76.81	80	0.46	2.32	100	DCI	J664	J599
P-390	93.57	80	0.46	2.32	100	DCI	J602	J601
P-391	118.26	80	0.46	2.32	100	DCI	J601	J664
P-341	30.18	100	0.16	1.26	100	DCI	J1429	J634
P-342	61.87	100	0.16	1.26	100	DCI	J634	J635
P-272	36.58	150	0.2	3.6	100	DCI	J151	J358
P-265	57.91	80	0.08	0.41	100	DCI	J374	J375
P-271	121.62	150	0.2	3.6	100	DCI	J358	II_Ch_5
P-346	113.08	100	0.5	3.91	100	DCI	J1425	J1426
P-347	40.54	100	0.5	3.91	100	DCI	J1426	J1427
P-345	131.98	100	0.5	3.91	100	DCI	J1424	J1425
P-343	122.83	100	0.5	3.91	100	DCI	J162	J1423
P-344	124.05	100	0.5	3.91	100	DCI	J1423	J1424
P-395	146.91	50	0.46	0.9	100	DCI	AsJ596	III_Ar_2
P-432	146.61	250	0.2	9.82	100	DCI	AsJ204	AsJ1149
P-434	203.61	100	0.59	4.65	100	DCI	III_Hn_10	III_Hn_5
P-431	10.36	250	1.03	50.76	100	DCI	III_Hn_11	AsJ204
P-425	137.16	150	0.93	16.38	100	DCI	J209	J210
P-426	145.69	80	1.04	5.23	100	DCI	J208	J209
P-451	23.77	100	1.09	8.55	100	DCI	J126	AsJ125
P-452	60.66	100	1.09	8.55	100	DCI	J125	J124
P-450	30.18	100	1.09	8.55	100	DCI	J127	J126
P-448	115.52	250	1.1	54.17	100	DCI	J131	III_Hn_11
P-449	93.27	100	1.09	8.55	100	DCI	J206	J127
P-412	78.03	150	0.15	2.72	100	DCI	J82	III_Br_1
P-417	217.32	100	0.86	6.76	100	DCI	III_Br_2	AsJ105
P-411	62.48	150	0.15	2.72	100	DCI	J83	J82

P-396	142.34	100	0.11	0.9	100	DCI	J595	J596
P-410	99.36	150	0.15	2.72	100	DCI	J100	J83
P-421	338.94	80	0.42	2.1	100	DCI	III_Br_3	J109
P-424	67.36	150	0.93	16.38	100	DCI	J210	J111
P-420	288.04	100	0.61	4.82	100	DCI	J208	III_Br_3
P-418	113.39	100	0.86	6.76	100	DCI	J105	J106
P-419	72.24	100	0.86	6.76	100	DCI	J106	J208
P-1385	206.35	150	0.2	3.45	100	DCI	J150	J-1221
P-1384	503.53	80	0.33	1.67	100	DCI	J139	J154
P-1386	176.78	80	0.69	3.45	100	DCI	J-1221	J194
P-1388	62.18	80	0.81	4.09	100	DCI	J-1224	J188
P-1387	148.44	80	0.23	1.18	100	DCI	J194	J-1224
P-1380	577.9	150	0.5	8.84	100	DCI	J164	J162
P-1372	234.7	150	0.42	7.38	100	DCI	St.Gebriel Reservoir	J74
P-1381	305.41	100	0.39	3.07	100	DCI	J162	II_Hl_3
P-1383	367.28	100	0.54	4.27	100	DCI	J159	J154
P-1382	295.35	100	0.34	2.68	100	DCI	II_Hl_3	J159
P-1398	126.49	250	0.53	25.8	100	DCI	J1018	J-1212
P-1397	707.14	350	0.57	54.78	100	DCI	St.Mery Reservoir	J1018
P-1399	81.99	300	0.82	57.66	100	DCI	J-1213	J1141
P-1402	324	150	0.72	12.72	100	DCI	J-1212	J-1220
P-1401	149.35	250	0.91	44.81	100	DCI	J-1212	J-1213
P-1392	199.34	80	0.86	4.3	100	DCI	J1187	J1192
P-1393	360.88	80	0.66	3.34	100	DCI	J299	J1170
P-1394	223.42	250	0.2	9.79	100	DCI	J1149	J683
P-1396	120.09	100	0.13	1.04	100	DCI	J214	J131
P-1395	144.17	250	0.68	33.47	100	DCI	J1148	J131
P-1376	89.92	100	0.22	1.77	100	DCI	Kebele-02 Condominiu m	J-1222
P-233	64.01	80	1.07	5.4	100	DCI	J183	II_Br_5
P-242	122.83	80	0.55	2.74	100	DCI	II_Br_4	J173
P-232	137.16	80	0.38	1.91	100	DCI	II_Br_5	J181
P-129	71.02	150	0.42	7.41	100	DCI	J1434	J31
P-145	150.57	150	0.42	7.41	100	DCI	J31	J164
P-263	25.91	80	0.08	0.41	100	DCI	J376	J377
P-264	35.97	80	0.08	0.41	100	DCI	J375	J376

P-262	49.99	80	0.08	0.41	100	DCI	J377	J154
P-249	98.45	80	0.81	4.09	100	DCI	J188	II_Br_4
P-258	119.18	150	0.81	14.39	100	DCI	J151	J150
P-90	140.51	150	0.41	7.23	100	DCI	J76	J1437
P-91	131.37	150	0.41	7.23	100	DCI	J1437	J1438
P-89	29.87	150	0.83	14.64	100	DCI	J75	J76
P-1375	106.98	100	0.22	1.77	100	DCI	J-1222	AsJ605
P-88	23.77	150	0.83	14.64	100	DCI	J74	J75
P-115	120.4	150	0.21	3.72	100	DCI	J1439	J20
P-128	65.53	150	0.42	7.41	100	DCI	J76	J1434
P-94	74.68	100	0.45	3.5	100	DCI	J1440	J1441
P-92	129.54	150	0.41	7.23	100	DCI	J1438	J1439
P-93	189.59	100	0.45	3.5	100	DCI	J1439	J1440
P-638	121.01	200	0.12	3.75	100	DCI	J683	III_Ar_4
P-639	197.21	200	0.02	0.54	100	DCI	III_Ar_4	J671
P-637	138.38	150	0.17	2.93	100	DCI	J954	J966
P-899	130.45	150	0.69	12.19	100	DCI	J587	J588
P-636	206.04	150	0.14	2.53	100	DCI	J966	J965
P-658	49.99	150	0.81	14.29	100	DCI	J536	J537
P-659	55.17	150	0.81	14.29	100	DCI	J537	J538
P-657	214.58	150	0.81	14.29	100	DCI	J535	J536
P-898	134.72	150	0.69	12.19	100	DCI	J588	J589
P-897	92.05	150	0.69	12.19	100	DCI	J589	J590
P-622	83.52	100	0.06	0.47	100	DCI	J654	J595
P-623	34.44	150	0.2	3.45	100	DCI	III_Ar_3	J674
P-619	35.36	150	0.4	7.13	100	DCI	J676	III_Ar_3
P-617	52.73	150	0.4	7.13	100	DCI	J678	J677
P-618	24.99	150	0.4	7.13	100	DCI	J677	J676
P-627	21.03	150	0.04	0.68	100	DCI	J594	J957
P-900	117.65	150	0.69	12.19	100	DCI	J541	J587
P-626	97.84	150	0.06	1.12	100	DCI	J955	J594
P-624	68.28	150	0.2	3.45	100	DCI	J674	J954
P-625	118.57	150	0.06	1.12	100	DCI	J954	J955
P-668	97.23	100	0.85	6.68	100	DCI	J581	J688
P-830	13.41	80	0.39	1.94	100	DCI	J1221	J1220
P-829	42.37	80	0.39	1.94	100	DCI	J1220	J896
P-831	61.57	80	0.39	1.94	100	DCI	J1222	J1221
P-833	13.72	80	0.39	1.94	100	DCI	J891	J1223
P-832	62.18	80	0.39	1.94	100	DCI	J1223	J1222

P-789	58.52	100	0.05	0.39	100	DCI	J872	J871
P-788	40.84	100	0.05	0.39	100	DCI	J871	J870
P-812	52.12	100	0.12	0.94	100	DCI	J896	J1218
P-814	171.91	100	0.13	1	100	DCI	J895	J872
P-813	143.87	100	0.13	1	100	DCI	J896	J895
P-869	189.59	150	0.45	8.03	100	DCI	J1411	J1198
P-868	71.32	150	0.65	11.41	100	DCI	J1412	J1411
P-870	56.39	150	0.45	8.03	100	DCI	J1198	J1197
P-669	89.92	100	0.85	6.68	100	DCI	J688	J687
P-670	91.74	100	0.42	3.32	100	DCI	J691	J690
P-844	49.38	100	0.48	3.78	100	DCI	J860	J861
P-843	48.16	100	0.48	3.78	100	DCI	J859	J860
P-845	121.92	100	0.48	3.78	100	DCI	J861	J862
P-867	107.29	150	0.65	11.41	100	DCI	J1413	J1412
P-846	123.44	100	0.48	3.78	100	DCI	J862	J1218
P-540	78.33	80	0.73	3.67	100	DCI	J1187	J1188
P-541	84.73	80	0.63	3.18	100	DCI	III_Bs_7	J300
P-533	151.79	80	0.05	0.23	100	DCI	J1171	J1170
P-527	64.92	80	0.86	4.3	100	DCI	J1192	J1172
P-532	104.24	80	0.05	0.23	100	DCI	J1172	J1171
P-572	60.66	100	1.4	11.03	100	DCI	J1163	III_Hn_16
P-573	146.61	100	0.97	7.62	100	DCI	III_Hn_16	J1161
P-545	128.93	80	0.62	3.14	100	DCI	Kebele-9 Condominium	III_Bs_6
P-542	150.57	80	0.63	3.18	100	DCI	J300	J299
P-544	173.13	80	0.8	4	100	DCI	III_Hn_3	Kebele-9 Condominium
P-462	213.97	80	0.45	2.28	100	DCI	III_Hn_19	J1187
P-1025	207.26	150	0.11	1.93	100	DCI	IV_Ar_1	J510
P-461	177.09	150	0.79	13.94	100	DCI	J112	III_Hn_19
P-453	42.06	150	0.48	8.55	100	DCI	J124	J123
P-460	20.12	150	0.89	15.75	100	DCI	J111	J112
P-989	110.03	150	1.06	18.8	100	DCI	IV_Ar_6	J495
P-522	48.46	80	0.73	3.67	100	DCI	J1188	J1187
P-990	71.93	150	1.06	18.8	100	DCI	J495	J494
P-992	178.61	150	1.06	18.8	100	DCI	J493	IV_Ar_1

P-991	131.06	150	1.06	18.8	100	DCI	J494	J493
P-574	158.8	100	0.97	7.62	100	DCI	J1161	J299
P-918	109.73	150	0.53	9.29	100	DCI	J573	J574
P-917	45.42	150	0.53	9.29	100	DCI	J572	J573
P-597	195.99	300	0.82	57.66	100	DCI	J1141	III_Ch_4
P-595	109.73	300	0.77	54.3	100	DCI	J659	AsJ1144
P-596	195.99	300	0.77	54.3	100	DCI	III_Ch_4	J659
P-608	126.19	100	0.11	0.86	100	DCI	III_Ch_3	J649
P-616	208.48	150	0.4	7.13	100	DCI	J679	J678
P-914	61.26	150	0.53	9.29	100	DCI	J569	J570
P-916	45.42	150	0.53	9.29	100	DCI	J571	J572
P-915	21.64	150	0.53	9.29	100	DCI	J570	J571
P-928	51.51	150	1.12	19.76	100	DCI	J540	J541
P-927	63.7	150	1.12	19.76	100	DCI	J539	J540
P-578	62.18	80	0.67	3.36	100	DCI	J1166	III_Hn_3
P-576	141.73	80	1.35	6.77	100	DCI	III_Hn_5	III_Hn_4
P-577	159.72	80	0.67	3.36	100	DCI	III_Hn_4	J1166
P-593	11.28	300	0.76	53.46	100	DCI	J1145	J1146
P-594	25.6	300	0.77	54.3	100	DCI	J1144	J1145
P-592	35.36	300	0.76	53.46	100	DCI	J1146	III_Hn_9
P-583	113.69	300	0.66	46.58	100	DCI	III_Hn_9	J1148
P-926	93.88	150	1.12	19.76	100	DCI	J538	J539
P-1403	396.54	150	0.65	11.47	100	DCI	J-1220	J662
P-1414	282.85	200	0.41	12.82	100	DCI	J514	J535
P-1411	134.72	150	0.25	4.35	100	DCI	J123	J209
P-1416	81.38	200	0.41	12.82	100	DCI	J513	J514
P-1390	280.11	80	0.09	0.43	100	DCI	J184	J173
P-1417	611.43	100	0.36	2.82	100	DCI	IV_Ar_1	J485
P-1405	126.8	150	0.37	6.47	100	DCI	J650	J679

APPENDIX D: WaterGEMS-Run Pipe Report

Label	Baseflow (l/s)	Easting (m)	Northing (m)	Elevation (m)	Pressure (mH2O)	Calculated Hydraulic Grade (m)
AsJ513		513,720.84	879,646.89	2,373.92	1.546	2,375.47
III_Br_3	2.72	515,304.33	878,811.36	2,453.65	1.583	2,455.23
IV_Hn_1	1.81	514,511.42	879,926.86	2,359.49	1.792	2,361.29
V_Ar_7	3.34	512,794.06	881,021.21	2,257.18	2.227	2,259.41
VI_Hl_2	1.97	516,105.04	876,056.26	2,667.82	2.642	2,670.46
II_Br_7	3.49	515,889.41	878,032.83	2,534.67	2.65	2,537.33
J1277		512,734.83	881,056.65	2,255.68	3.843	2,259.53
J700		516,217.57	883,247.16	2,278.62	4.615	2,283.25
J514		513,650.56	879,688.13	2,370.05	5.267	2,375.33
IV_Km_1	3.09	513,586.68	878,922.39	2,356.19	5.778	2,361.98
J1039		513,726.84	881,782.30	2,259.57	6.264	2,265.85
III_Bs_8	3.34	515,778.13	879,431.73	2,439.82	6.439	2,446.27
J1040		513,658.76	881,727.79	2,259.02	6.468	2,265.50
IV_Km_3	3.09	513,460.35	878,454.70	2,346.53	6.655	2,353.20
J688		514,141.51	880,008.39	2,358.10	6.667	2,364.78
J1041		513,548.85	881,771.01	2,257.76	7.25	2,265.02
III_Bs_1	3.34	516,383.45	881,052.79	2,425.85	7.251	2,433.12
J1337		512,965.19	878,259.19	2,351.41	7.299	2,358.72
J427		513,141.02	881,537.85	2,253.59	7.531	2,261.13
IV_Bs_1	2.94	514,920.62	880,505.28	2,350.35	7.675	2,358.04
V_Ar_4	3.34	511,897.21	880,290.70	2,242.55	7.691	2,250.26
J477		513,329.76	878,409.34	2,346.84	8.501	2,355.36
J1404		515,146.67	880,732.64	2,347.39	8.85	2,356.26
J978		514,103.60	880,236.77	2,357.05	9.022	2,366.09

Label	Baseflow (l/s)	Easting (m)	Northing (m)	Elevation (m)	Pressure (mH2O)	Calculated Hydraulic Grade (m)
J581		514,080.02	879,932.95	2,357.06	9.126	2,366.21
V_Ar_8	3.34	512,362.05	880,674.44	2,245.66	9.378	2,255.06
IV_Hn_2	1.81	514,527.91	880,071.56	2,351.98	9.631	2,361.63
J855		514,073.72	881,837.61	2,258.02	9.789	2,267.83
J1419		514,773.82	880,398.32	2,349.74	9.8	2,359.56
J1420		514,816.24	880,424.80	2,349.29	9.834	2,359.14
V_Wa_10	3.31	513,139.54	881,666.85	2,251.24	10.146	2,261.40
J1338		512,992.04	878,277.46	2,348.34	10.62	2,358.98
IV_Wa_8	3.36	514,210.18	880,066.38	2,352.75	10.693	2,363.46
J1276		512,798.49	881,212.12	2,249.06	10.731	2,259.81
J306		516,118.14	880,460.95	2,427.08	10.923	2,438.02
J252		515,785.31	878,101.39	2,526.32	11.324	2,537.67
J701		516,139.09	883,283.63	2,271.59	11.481	2,283.09
J95		514,562.37	878,213.17	2,453.09	11.549	2,464.67
J305		516,042.78	880,391.97	2,427.09	11.564	2,438.68
J1038		513,836.46	881,868.63	2,254.76	11.624	2,266.41
J304		515,982.33	880,196.04	2,428.20	11.773	2,439.99
J690		514,287.25	880,116.24	2,351.28	11.791	2,363.09
J976		514,351.99	880,262.99	2,351.37	12.013	2,363.41
J838		513,478.45	881,798.83	2,252.04	12.657	2,264.72
J1336		512,893.13	878,123.30	2,344.71	12.762	2,357.50
J582		513,981.05	879,994.21	2,354.46	12.773	2,367.26
J1043		513,427.51	881,815.35	2,251.61	12.791	2,264.43
J1283		512,044.72	880,413.99	2,238.57	13.094	2,251.69
J1037		513,970.26	881,977.04	2,253.94	13.129	2,267.10

Label	Baseflow (l/s)	Easting (m)	Northing (m)	Elevation (m)	Pressure (mH2O)	Calculated Hydraulic Grade (m)
III_Hl_1	2.66	513,155.97	876,628.80	2,438.55	13.378	2,451.95
V_Ar_6	3.34	512,522.89	880,804.86	2,245.60	13.394	2,259.02
J1181		515,973.50	880,162.98	2,426.61	13.582	2,440.22
J1304		514,841.94	882,178.07	2,258.54	13.683	2,272.25
J1180		515,969.59	880,170.97	2,426.44	13.703	2,440.17
J96		514,510.64	878,242.98	2,451.00	13.724	2,464.75
J1399		514,860.44	880,592.84	2,343.62	13.855	2,357.50
J98		514,393.67	878,118.78	2,451.26	13.885	2,465.17
V_Ar_5	3.34	512,208.44	880,548.14	2,239.24	13.992	2,253.26
J111		515,211.17	879,260.15	2,437.28	14.011	2,451.32
J854		513,994.02	881,951.01	2,252.97	14.246	2,267.24
J1405		515,207.29	880,861.79	2,341.23	14.293	2,355.55
J1255		516,255.14	882,579.80	2,327.46	14.477	2,341.96
J39		514,382.24	875,689.38	2,542.42	14.553	2,557.01
J1413		514,575.67	880,462.70	2,344.48	14.682	2,359.19
J856		514,163.47	881,916.08	2,253.30	14.994	2,268.33
J1303		514,711.14	882,149.50	2,256.23	15.072	2,271.33
I_Br_4	2.98	516,397.07	877,667.10	2,591.59	15.073	2,606.69
J1044		513,358.85	881,855.06	2,248.77	15.205	2,264.00
J210		515,178.93	879,200.97	2,436.68	15.334	2,452.04
J254		515,617.33	878,055.28	2,524.92	15.594	2,540.54
J47		514,236.39	874,562.10	2,534.73	15.597	2,550.36
J112		515,220.94	879,277.58	2,435.40	15.684	2,451.12
J109		515,464.18	879,110.23	2,437.74	15.736	2,453.51
J48		514,167.85	874,469.95	2,533.91	15.795	2,549.74

Label	Baseflow (l/s)	Easting (m)	Northing (m)	Elevation (m)	Pressure (mH2O)	Calculated Hydraulic Grade (m)
J459		513,439.36	878,874.48	2,347.09	15.846	2,362.97
J1186		515,616.65	879,518.75	2,431.70	15.903	2,447.63
J1271		517,055.80	884,377.50	2,253.73	15.95	2,269.71
J1026		514,275.04	881,947.95	2,252.99	15.966	2,268.99
J478		513,261.49	878,374.68	2,340.53	15.99	2,356.55
J1010		514,629.96	876,309.73	2,537.92	16.144	2,554.10
J72		515,961.56	876,136.98	2,655.44	16.252	2,671.72
J1025		514,303.31	881,958.34	2,252.81	16.281	2,269.12
J1403		515,087.74	880,607.46	2,340.47	16.429	2,356.94
J1339		513,076.36	878,297.87	2,343.06	16.579	2,359.67
J263		515,179.05	877,455.10	2,532.89	16.595	2,549.51
J38		514,366.45	875,691.30	2,540.24	16.698	2,556.97
J1418		514,634.60	880,306.22	2,344.12	16.807	2,360.96
J332		516,270.14	880,891.43	2,417.73	16.823	2,434.58
J977		514,204.41	880,371.76	2,347.96	16.875	2,364.87
J816		515,041.22	882,512.31	2,258.26	16.911	2,275.20
III_Br_1	2.72	514,751.11	878,104.94	2,447.07	16.964	2,464.06
J515		513,568.53	879,742.36	2,358.17	16.965	2,375.16
J583		513,948.19	880,019.66	2,350.57	17.024	2,367.63
J1438		514,246.76	875,378.52	2,538.57	17.073	2,555.68
J819		515,153.97	882,655.07	2,258.84	17.279	2,276.15
J49		514,042.18	874,530.82	2,531.66	17.294	2,548.99
J817		515,009.39	882,550.50	2,258.00	17.373	2,275.41
J1335		512,819.44	878,014.22	2,338.88	17.541	2,356.45
J1021		514,600.27	882,112.59	2,252.97	17.608	2,270.61

Label	Baseflow (l/s)	Easting (m)	Northing (m)	Elevation (m)	Pressure (mH2O)	Calculated Hydraulic Grade (m)
J822		515,343.21	882,858.34	2,259.90	17.633	2,277.57
J1414		514,565.60	880,420.48	2,342.55	17.662	2,360.24
J1302		514,631.26	882,126.29	2,253.03	17.692	2,270.75
J426		513,140.55	881,363.20	2,243.03	17.7	2,260.77
J1402		515,067.20	880,631.41	2,339.35	17.705	2,357.09
J691		514,331.61	880,150.11	2,345.18	17.736	2,362.96
J1024		514,359.94	881,940.01	2,251.57	17.767	2,269.37
J1045		513,290.18	881,894.76	2,245.70	17.838	2,263.58
J253		515,687.69	878,164.76	2,520.09	17.853	2,537.98
J1036		514,133.74	882,106.14	2,250.45	17.911	2,268.40
J197		515,184.88	879,295.70	2,433.65	17.938	2,451.62
J980		513,934.73	880,196.41	2,349.89	17.945	2,367.87
J46		514,314.01	874,651.22	2,533.00	17.961	2,551.00
J1412		514,545.52	880,565.57	2,340.56	18.009	2,358.60
J1468		517,214.89	884,552.07	2,250.58	18.064	2,268.68
J50		513,997.87	874,553.89	2,530.43	18.255	2,548.72
J1279		512,600.92	880,870.42	2,240.79	18.312	2,259.14
J1009		514,585.60	876,208.96	2,535.92	18.356	2,554.31
III_Br_4	2.72	515,382.15	879,152.47	2,432.17	18.452	2,450.66
J857		514,245.15	881,987.38	2,250.25	18.495	2,268.78
J20		514,130.49	875,268.31	2,536.74	18.516	2,555.29
VI_Hl_1	1.97	515,657.03	875,418.81	2,662.81	18.567	2,681.41
J1003		514,684.02	876,504.92	2,534.93	18.651	2,553.62
J429		513,138.07	881,795.84	2,243.20	18.656	2,261.89
J94		514,620.09	878,187.10	2,445.85	18.684	2,464.57

Label	Baseflow (l/s)	Easting (m)	Northing (m)	Elevation (m)	Pressure (mH2O)	Calculated Hydraulic Grade (m)
J703		515,959.72	883,184.70	2,263.76	18.696	2,282.49
J1002		514,745.54	876,622.50	2,534.53	18.796	2,553.36
J1035		514,169.75	882,137.20	2,249.79	18.875	2,268.70
J1417		514,607.94	880,324.80	2,342.11	19.085	2,361.23
J1398		514,803.15	880,676.98	2,337.79	19.153	2,356.98
J447		513,119.55	876,631.43	2,432.81	19.274	2,452.13
J779		516,048.53	883,330.56	2,263.43	19.444	2,282.91
J1406		515,116.13	880,980.19	2,335.06	19.721	2,354.82
J983		513,710.71	879,932.05	2,351.69	19.765	2,371.49
J255		515,580.96	878,004.88	2,521.84	19.89	2,541.77
J821		515,236.72	882,782.37	2,256.95	20.033	2,277.02
J818		515,097.59	882,615.97	2,255.68	20.149	2,275.87
J1401		515,028.20	880,597.09	2,337.12	20.186	2,357.35
J1305		514,790.63	882,221.99	2,252.36	20.314	2,272.71
J1253		516,111.93	882,349.38	2,322.40	20.332	2,342.77
J1439		514,249.27	875,249.08	2,535.00	20.335	2,555.37
J839		513,469.59	881,973.22	2,245.06	20.427	2,265.53
J1185		515,733.98	879,744.68	2,423.76	20.508	2,444.31
J425		512,922.13	881,342.53	2,239.72	20.545	2,260.31
II_Br_1	3.49	515,252.85	877,485.93	2,528.65	20.556	2,549.25
J1334		512,791.04	877,998.79	2,335.57	20.589	2,356.20
J209		515,116.43	879,079.04	2,432.74	20.731	2,453.51
J1345		512,649.74	878,173.72	2,335.63	20.824	2,356.49
J1437		514,243.84	875,509.78	2,534.90	21.043	2,555.99
J1411		514,516.09	880,630.64	2,337.05	21.12	2,358.21

Label	Baseflow (l/s)	Easting (m)	Northing (m)	Elevation (m)	Pressure (mH2O)	Calculated Hydraulic Grade (m)
J1254		516,131.84	882,383.40	2,321.31	21.301	2,342.65
J1008		514,505.70	876,032.60	2,533.31	21.325	2,554.68
J979		514,013.26	880,304.46	2,345.53	21.331	2,366.90
J260		515,290.27	877,523.14	2,527.21	21.348	2,548.60
II_Hl_1	3.5	513,951.41	874,485.04	2,526.65	21.353	2,548.04
J264		515,149.46	877,455.20	2,528.03	21.538	2,549.61
J1022		514,517.63	882,059.76	2,248.53	21.623	2,270.20
J443		514,136.86	882,191.55	2,247.53	21.743	2,269.32
J82		514,775.10	878,179.07	2,442.03	22.017	2,464.09
J852		513,864.83	882,094.10	2,246.09	22.115	2,268.25
J83		514,788.49	878,239.97	2,441.93	22.143	2,464.12
J460		513,330.65	878,837.94	2,341.52	22.146	2,363.71
J1306		514,871.18	882,315.90	2,251.37	22.155	2,273.57
J135		514,699.02	878,575.73	2,441.51	22.185	2,463.74
J1209		515,437.22	875,668.59	2,616.21	22.22	2,638.47
J975		514,411.43	880,229.91	2,340.55	22.271	2,362.87
J1467		517,174.03	884,572.12	2,246.17	22.274	2,268.49
J430		513,138.18	881,923.12	2,239.99	22.337	2,262.37
J1394		515,031.97	880,951.54	2,332.71	22.348	2,355.10
J1179		515,908.32	880,217.40	2,416.07	22.401	2,438.52
J974		514,425.34	880,210.47	2,340.20	22.434	2,362.68
IV_Ar_9	3.38	513,779.97	880,007.96	2,348.43	22.561	2,371.04
J92		514,629.92	878,220.12	2,441.88	22.595	2,464.52
J1416		514,569.23	880,361.25	2,338.99	22.643	2,361.67
J694		514,559.66	880,358.58	2,338.93	22.784	2,361.76

APPENDIX E: St. Merry reservoir located in kebele

APPENDIX F: Gebriel reservoir located in kebele-12

APPENDIX G: Red cross reservoir located in kebele- 04

APPENDIX H: Stand pipe fixed on the water main to serve the communities in buseta kebele

APPENDIX I: Walkessa kebele communities to fetch water at Asella public fountain

APPENDIX J: Exposed and damaged double orifice air valve in Mero dengego zone

APPENDIX K: Ashebeka gravity main intake weir and trash

APPENDIX L: Questionnaires for interviews used in customer satisfaction surveys

This survey is being created in order to carry out research for the MSc program at Adama Science and Technology University Institute in the Water Resources Engineering department within the School of Civil Engineering and Architecture. The primary goal of the study assessing the existing state of the water supply system in Asella town. As a result, I would like to ask that you please do not hesitate to provide me with accurate and true facts. I really appreciate your awareness!

Customer satisfaction surveys on the water supply are one way to measure the effectiveness of an urban water delivery system; the town of Asella serves as an example.

1) Are you drinking from the pipe water?

   Yes

   No

2) Does the water supply office respond earlier for your question on maintenance?

   Yes

   No

3) How many months do you wait after applying for a water meter before receiving one? Five months, two months, one week, or one month?
4) How many days a week do you get water? And how many hours a day, for two, four, six, or all days?
5) How satisfied are you with the water supply service?

very satisfied, satisfied, somewhat satisfied and not satisfied?

6) How much water is used up in litter each day?

Less than fifty,

Fifty to one hundred,

One hundred to five hundred, and

More than five hundred litters

7) About how far is it to fetch water, measured in meters?

<10 m,

10-100 m,

100 m -1 km,

More than a kilometer

8) In what amount of time (minutes) does fetching water take?

Less than five minutes,

A maximum of five to thirty minutes, or

Above thirty minutes